RSM Extraction and Adjustment of Large Field of View Frame Imagery

September 30, 2006

Charles Taylor, BAE Systems
John Dolloff, BAE Systems
Michelle Iiyama, BAE Systems
Ed Mikhail, Purdue University

BAE SYSTEMS

National Security Solutions P.O. Box 509009 San Diego, CA 92150-9009 USA
Telephone (858) 675-2600

Table of Contents

Table of Figures

Table of Tables

Table 3-1: Aerial Frame Camera Specifications 11

Table 3-2: Nadir Absolute Geopositioning Comparison Statistics 14

Table 3-3: Nadir Relative Geopositioning Comparison Statistics 14

Table of Appendix Tables

1.0Preface

Replacement Sensor Model (RSM) performance has been successfully verified for a number of tactical sensors and commercial satellite sensors. The tactical sensor performance reports are classified and therefore their audience is strictly limited. The following assesses RSM performance for an unclassified low-altitude airborne sensor. In terms of imaging geometry (platform position), it is similar to many tactical sensors. However, this sensor is also challenging in that it has a large field-of-view. Both nadir and oblique imaging geometries are also addressed, where the latter includes imaging the horizon.

2.0Introduction

A study was conducted of RSM target extraction and triangulation (adjustability) performances for large field-of-view (FOV) frame images. The goal of the study is to show that the RSM performance meets its charter for these images. The RSM charter is to provide image projective functionality (ground-to-image and image-to-ground), error propagation (accuracy prediction), and adjustability that are virtually equivalent to that of the original physically-based sensor model within the RSM operational assumptions.

There are two operational assumptions for RSM. The first is that the original sensor model is available at the point in the processing chain at which the RSM (image) support data are generated. That is, there is no provision for "resecting" the RSM support data from a few ground control point measurements.

The second operational assumption is that high-fidelity adjustability is realized only where the change in the model's operating point due to adjustment doesn't have too large of an effect on the sensor model partial derivatives, typically at the 1 % level. This assumption means that if the original sensor model support data are of very low fidelity, it is advisable to "resect" or triangulate the original sensor model prior to generating RSM support data.

In terms of partial derivates, fidelity is relative to the particular imaging geometry. For example, the *a priori* position contained in the support data for a space-borne sensor can be in error on the order of 1000 meters and not cause a fidelity problem regarding RSM adjustability. On the other hand, this tolerance may reduce to tens of meters for low-altitude airborne sensors.

In summary, and stating the RSM charter in a slightly different way, target extraction (including accuracy prediction) based on RSM is to be virtually identical to target extraction based on the original sensor model. Furthermore, RSM triangulation is also to be virtually identical to the corresponding original sensor model triangulation assuming that the original sensor model's *a priori* support data are reasonably accurate.

The study is based on 12 aerial frame images over the Purdue University campus provided by Professor Ed Mikhail. The images are a challenging test case for RSM because their fields of view approach ninety degrees. With such a large field of view, the imaging geometry changes substantially from one part of the image to another. It is within the RSM charter to have high fidelity even under these conditions, and demonstrating that it does is a major goal of this performance test.

The study is in three main parts. The first part uses the original nadir imaging geometry in four test scenarios. The second part focuses on RSM triangulation performance, in order to see whether or not the performance for these images is limited by the accuracy of the original frame sensor model support data (according to the second operating assumption). In the third part, the image support data and measurements are modified to simulate highly oblique imaging geometry, and once again, RSM triangulation performance is assessed.

The organization of the report is as follows. First, the test scenarios are defined. Next, the results of the three main parts of the study are presented. The report concludes with general RSM references, followed by an appendix of tables of detailed study results and statistics.

3.0RSM Performance Tests

The geopositioning operation of "target extraction" consists of estimating the three-dimensional positions, and their uncertainties, of points (targets) based on their measurements in images. The sources of error that enter into the estimation of the uncertainties (accuracy prediction) are the image support data uncertainties and the uncertainties in the image measurements. The image support data uncertainties are expressed in terms of the uncertainties of adjustable parameters, but the parameters are not actually adjusted in the operation of target extraction.

The geopositioning operation of triangulation consists of simultaneously estimating the three-dimensional positions of points and adjusting image support data parameters. Triangulation also includes estimating the uncertainties of the positions and the support data adjustments.

In general, the uncertainties of positions and adjustable parameters are quantified by error covariance matrices. For this performance study, the metrics of absolute and relative horizontal circular error (CE90) and vertical linear error (LE90) are distilled from the covariance matrices estimated in target extraction and triangulation.

3.1General Comparison Scenarios

Within its operational assumptions, RSM is designed to support the same estimation of point positions and their uncertainties, and allow sensor model parameter adjustment, and provide virtually the same results as the original sensor model it replaces. In this performance study, the RSM performance was analyzed in four scenarios of increasing complexity, as described below.

The simplest scenario is the Replace/Extract scenario. In this scenario, illustrated in , the original sensor models are used for target extraction with a set of image measurements. Next, the original sensor models are provided to the RSM Generator and RSM support data are generated. Then, another target extraction operation is performed, with the same image measurements as the previous target extraction, but with the RSM support data rather than the original support data. Finally, the absolute and relative point positions and uncertainties are compared to determine how well the goals of RSM performance are met.

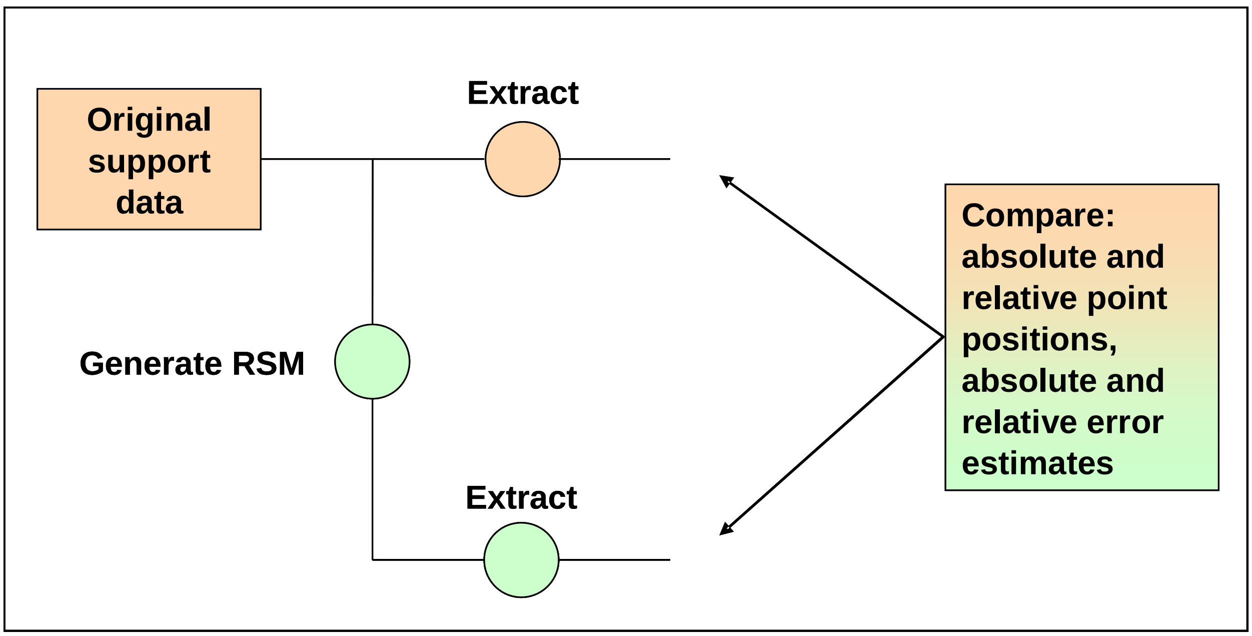

Figure 3-1: Replace/Extract Scenario

The Replace/Extract scenario described above uses the original support data, assumed not to have been previously triangulated. RSM is also designed to work with triangulated original sensor models. In the Triangulate/Replace/Extract scenario illustrated in Figure 3-2, a triangulation operation has been inserted ahead of the RSM Generation and extraction operations. The triangulation may include any combination of tie points and ground control points. The RSM Generator takes in both the triangulated original sensor models and the joint covariance matrix from the triangulation, and otherwise the operations are as in the Replace/Extract scenario.

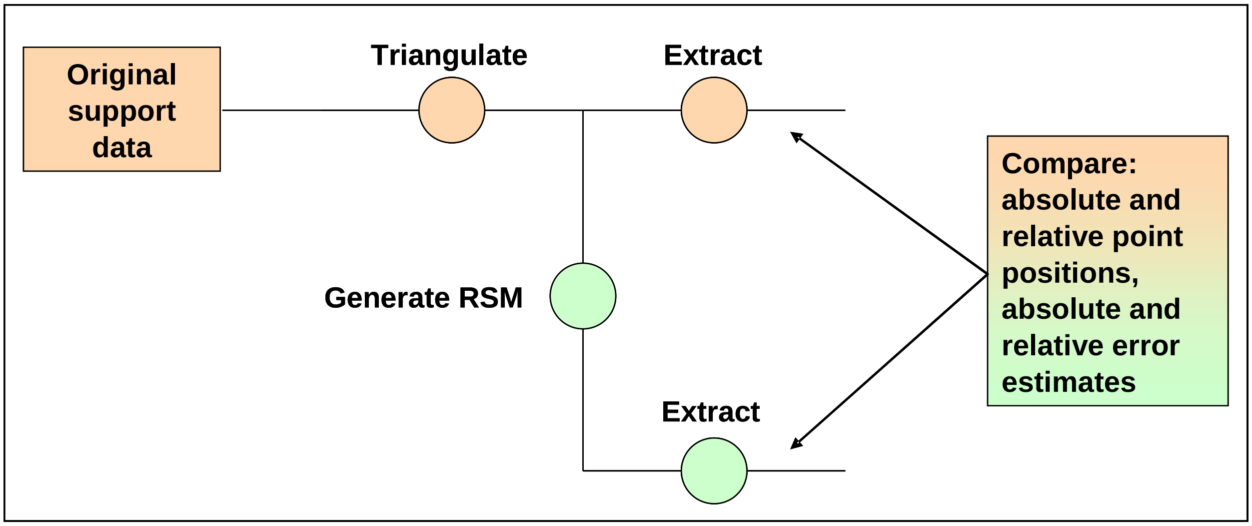

Figure 3-2: Triangulate/Replace/Extract Scenario

The Replace/Triangulate scenario, like the Triangulate/Replace/Extract scenario, begins with triangulation of the original sensor models, using tie points and/or ground control points. But after that it differs as shown in Figure 3-3, because in the Replace/Triangulate scenario the RSM Generator is given the un-triangulated original sensor models. Then, the RSM support data are used in a triangulation using the same tie and/or ground control points as the original sensor model triangulation. The performance is analyzed based on the tie points used in both triangulations—if the RSM goals are met then their positions and error estimates will be virtually the same.

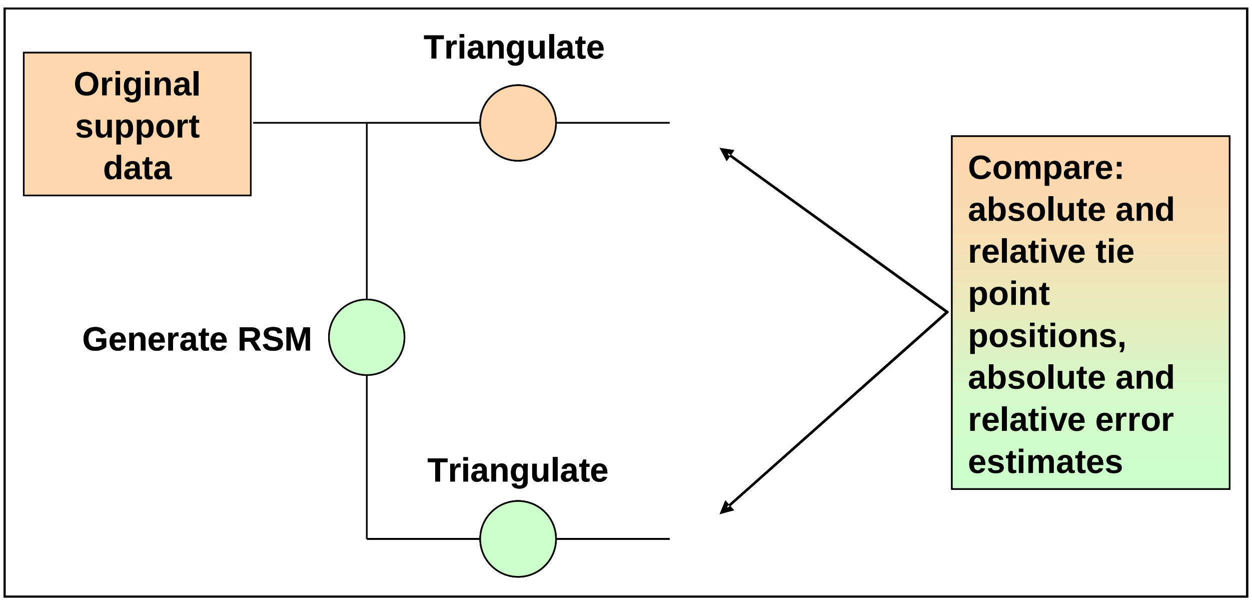

Figure 3-3: Replace/Triangulate Scenario

The RSM support data format is designed to retain the parameter adjustments and the *a posteriori* joint error covariance from triangulation, and this capability is used in the Replace/Triangulate/Extract scenario, shown in Figure 3-4. It begins with the same operations as in the Replace/Triangulate scenario, and then a target extraction is performed with the triangulated original sensor models. A target extraction with the same image measurements is performed with the triangulated RSM sensor models, and the absolute and relative target positions and uncertainties are compared. The performance is expected to be about the same as for the Triangulate/Replace scenario, since no additional support data improvement happens in the target extraction operation, but the scenario is more complex operationally, because the adjustments and joint *a posteriori* error covariance need to be passed from triangulation to target extraction.

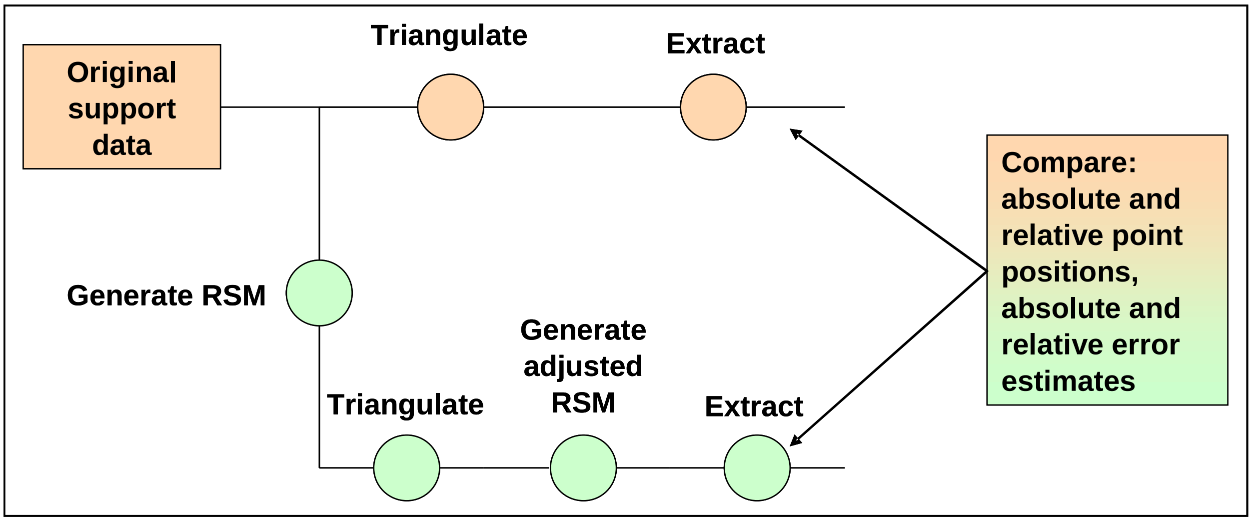

Figure 3-4: Replace/Triangulate/Extract Scenario

3.2Nadir Geometry Test Case

The 12 test images were obtained with the aerial frame camera whose specifications are given in Table 3-1. The camera was nadir-looking, and the platform was flown in a north-south direction. The platform height is around 800 m and the terrain height is around 200 m, so the platform is about 600 m above the ground. The full field of view is about 88 degrees in both directions (row and column, or line and sample). The image sizes are about 7700 pixels in each direction, and the ground sample distances (GSDs) are around 0.11 m. A more complete table of image geometry data is in the appendix in Table A.1 - .

Table 3-1: Aerial Frame Camera Specifications

Category	Specifications
Camera	Wild RC-10
Calibrated Focal Length	153.077 mm
Format	230 mm x 230 mm (9"x9")
Average Scale	1:4000
Scanned at pixel size	30 microns
Date	October 1999
Forward Overlap	80 %
Sidelap	60 %

The footprints of the test images are plotted in Figure 3-5. The figure also shows the locations of the ground control points, tie points, and check points that are described in the following paragraphs.

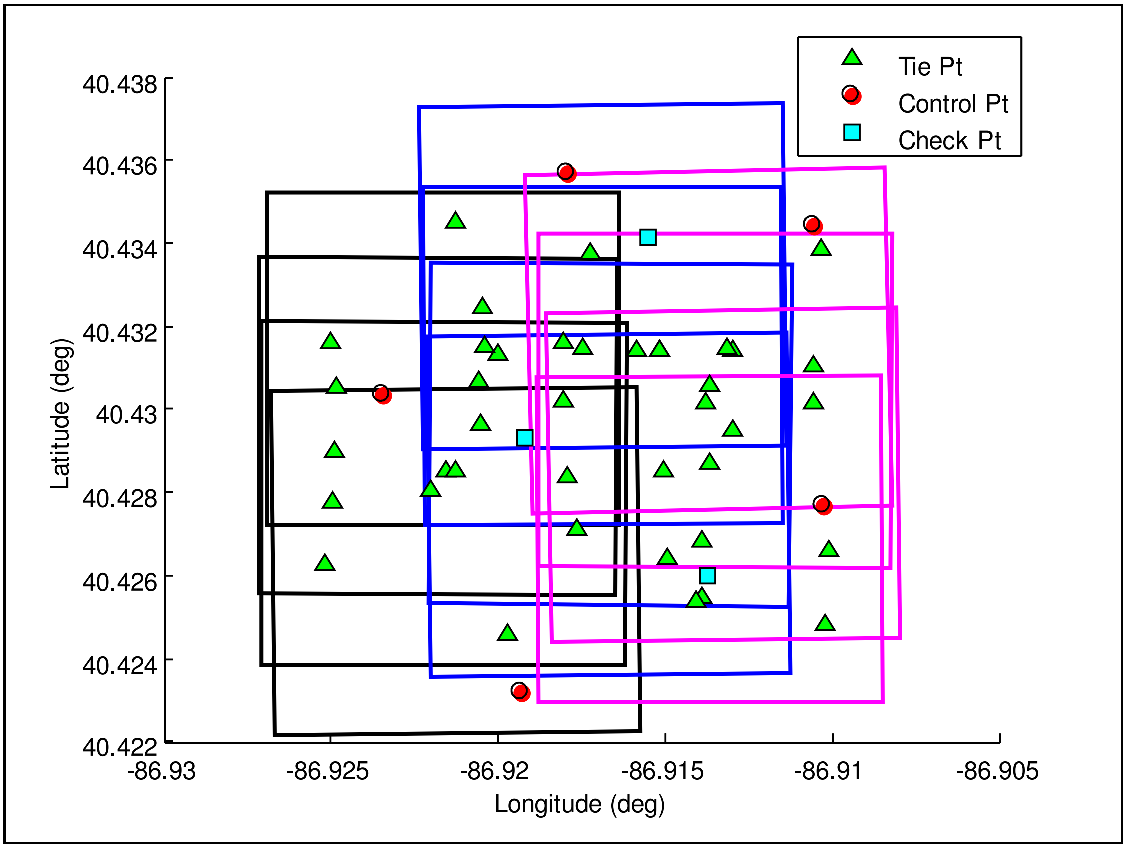

Figure 3-5: Image Footprints and Ground Points

When triangulation is included in a scenario, the images are triangulated with 5 surveyed ground control points, whose point identifiers are HISC (measured in 1 image), PH11 (3 images), LILY (1 image), BBLL (4 images), and STNE (2 images). Thus there are a total of 11 control point measurements. The control point error estimate is 0.1 m (1 standard deviation) in each horizontal component and 0.3 m in the vertical component. The control point uncertainties are modeled as uncorrelated between pairs of control points.

In addition to the control points, the triangulations use 40 tie points. The tie points are measured in two to ten images each, for a total of 186 tie point measurements.

Three surveyed check points are used in the target extraction operations, and these points are not included in the triangulations. Their point identifiers are PH12 (measured in 7 images), CHEM (3 images), and MACK (3 images). The check point error estimates are the same as the control point error estimates, except for MACK, which has error estimates of 0.3 m (1 standard deviation) in each horizontal component and 0.5 m in the vertical component. The surveyed coordinates of the check points are available for "ground truth" comparisons, but the main emphasis of the study is the comparison of RSM and original sensor model performance.

Image measurement errors are all taken to be 0.5 pixel one-standard-deviation in the line and sample directions for all measurements. This was done in the absence of any measurement error estimates in the data provided for the study. Metrics internal to triangulation indicate these error estimates are reasonable.

The first operational assumption for RSM is that an original physically-based sensor model must be available in the processing sequence when the RSM support data are generated. In this study, this requirement was met through the use of a rigorous frame sensor model with six adjustable parameters, along with its *a priori* image support data. The adjustable parameters are east-north-up (ENU) sensor position corrections and omega, phi, kappa euler angle corrections for the camera attitude. The baseline *a priori* uncertainties are set to 30 m (one standard deviation) for position corrections and 0.05 rad (one standard deviation) for angle corrections. The errors are assumed to be uncorrelated between images.

The frame sensor model adjustable parameter error estimates were obtained by engineering judgment when it was found that the error estimates originally provided were too large (too conservative). The error estimates originally provided were sensor model defaults not applicable to the specific scenario. They were 1225 m for each component of the sensor position and 1.53 rad for each attitude angle. An initial triangulation was performed with these error estimates, and the ratios of the sensor parameter adjustments to the *a priori* error estimates were found to be so small that the error estimates were statistically unreasonable. Thus, the *a priori* adjustable parameter error estimates were overly conservative. The same metric (ratio of sensor parameter adjustments to error estimates) showed that the revised error estimates in the preceding paragraph were reasonable.

The second operational assumption for RSM, which relates to RSM adjustment, is that the change in the model's operating point due to adjustment affects the sensor model partial derivatives below about the 1 % level. The original sensor model error estimates suggest this will be exceeded by about a factor of five, as it will be shown, and therefore it is anticipated that some differences between original and RSM performance will be seen in RSM triangulations.

RSM support data were generated independently for the 12 images. The projective model selected and fit by the RSM Generator was a linear rational polynomial in rectangular coordinates. Root-mean-square (RMS) and maximum fitting errors (as compared with the original frame sensor model) were well under 0.001 pixels, both on the grid of fit points and with a random sampling of 1000 evaluation points per image.

The RSM adjustable parameters selected by the RSM Generator were ground-space adjustable parameters: translation (in three dimensions) and small-angle rotations about three orthogonal axes as defined in the RSM TRE specification. Thus there were a total of six RSM adjustable parameters per image.

The RSM generation, triangulation, target extraction, and original frame sensor modeling were done within BAE Systems' Real-Time Automated Geopositioning Environment (RAGE) rapid prototyping baseline (Socet Set and the Joint Targeting Workstation (JTW) were not used). In addition, the BAE/NGA RSM Generator and BAE/NGA RSM Exploiter modules were used.

3.2.1Results Using Baseline *A Priori* Support Data

The first set of results uses the baseline *a priori* image support data as described above (30m and 0.05 rad one-standard-deviation frame sensor model adjustable parameter error estimates). The absolute and relative geopositioning comparison statistics between original sensor model and RSM tests are given in Table 3-2 and Table 3-3 for the four scenarios and additional details are contained in the appendix.

In the following tables, the reference (Ref) columns apply to the original sensor model and the comparison (Comp) columns apply to RSM. The horizontal difference (Horiz diff) is the distance from the target's horizontal position as determined in original sensor model operations to the target's horizontal position as determined in RSM operations, and should be viewed in the context of the horizontal circular error estimate (CE). The vertical difference (Vert diff) is the offset of the height obtained in RSM operations with respect to the height obtained in original sensor model operations, and should be viewed in the context of the vertical linear error estimate (LE).

Table 3-2: Nadir Absolute Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Extract	RMS	75.178	75.154	145.935	146.003	0.074	0.137
	max	97.118	97.096	183.982	184.117	0.114	0.220
Triangulate/Replace /Extract	RMS	0.213	0.213	0.444	0.441	0.000	0.001
	max	0.241	0.241	0.517	0.513	0.000	0.001
Replace/Triangulate	RMS	0.256	0.255	0.498	0.496	0.235	0.298
	max	0.539	0.537	0.852	0.843	0.999	1.268
Replace/Triangulate /Extract	RMS	0.213	0.213	0.444	0.441	0.110	0.252
	max	0.241	0.241	0.517	0.517	0.155	0.419

Table 3-3: Nadir Relative Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Extract	RMS	103.666	103.628	209.951	210.068	0.121	0.191
	max	123.962	123.931	245.089	245.220	0.158	0.270
Triangulate/Replace /Extract	RMS	0.246	0.246	0.532	0.531	0.000	0.002
	max	0.299	0.299	0.661	0.660	0.000	0.003
Replace/Triangulate	RMS	0.302	0.302	0.570	0.566	0.326	0.415
	max	0.725	0.725	1.264	1.238	1.370	1.851
Replace/Triangulate /Extract	RMS	0.246	0.246	0.532	0.522	0.167	0.403
	max	0.299	0.299	0.661	0.646	0.235	0.542

The Replace/Extract scenario comparison statistics are in the first two lines of Table 3-2 and Table 3-3. For this scenario, the statistics are with respect to the three check points. The RMS absolute CE of about 75 m and absolute LE of about 146 m in Table 3-2 are large, due to the large *a priori* support data uncertainty, as there is no triangulation in this scenario. The RSM support data generation and extraction reproduces these figures to within much less than one meter. Also, the horizontal and vertical absolute target position differences are much less than one meter, and far less than the absolute CE and LE. Likewise, the RMS relative CE of about 104 m and relative LE of about 210 m in Table 3-3 are reproduced very well by the RSM extraction, and the relative solution differences are much less than one meter. As expected, the maximum statistics for the three check points are a little larger than the RMS statistics.

The Replace/Extract scenario discussed above is a challenging test case for several reasons. The target extraction is done with optimal weighting according to the support data uncertainty for each image and the uncertainty of each measurement, and not with simplifying assumptions such as equal weighting for each image. All twelve images are involved when the three points are extracted simultaneously, and there are at least three measurements for each check point. Therefore this case requires more than just high fidelity of the RSM ground-to-image projective function to the original projective function; it also requires high fidelity of the RSM adjustable parameter error covariance to the original sensor model error covariance for every image. The RSM performance is in close agreement with the original in this challenging case.

The second scenario, Triangulate/Replace/Extract, is considered next. In this scenario, the five control points, together with the tie points between the images, result in very accurate adjusted original support data. In Table 3-2 this is seen in the RMS CE of about 0.2 m and RMS LE of about 0.4 m. Also, Table 3-3 shows that the relative CE is about 0.2 m and the relative LE is about 0.5 m. The RSM tests show that the original sensor model geopositioning is reproduced with extraordinarily high fidelity in this scenario. All differences between original (reference) and RSM (comparison) positions and error estimates are well under 0.01 m.

The Triangulate/Replace/Extract performance is in line with other studies that show this to be a very favorable scenario for RSM. Note also that the original sensor multi-image (adjustable parameter) support data error covariance reflects a highly correlation between images following triangulation (as it should) and that the corresponding RSM multi-image error covariance successfully represented this error covariance with high fidelity.

For the Replace/Triangulate scenario, the statistics are evaluated over the 40 tie points (rather than the three check points used in the other three scenarios). Thus, the RMS statistics are more significant and representative than for the other three scenarios, and the maximum statistics lie further from the RMS than in the other three scenarios. In this scenario, Table 3-2 shows that the RMS absolute CE and LE are about 0.25 m and 0.5 m, respectively, and that the RSM computations of CE and LE are in excellent agreement with those obtained from the original sensor models. The RMS difference in absolute horizontal positions between original and RSM computations is about 0.2 m in this scenario, and the RMS difference in absolute vertical positions is about 0.3 m. The largest difference in absolute horizontal positions for the 40 tie points is about 1.0 m, and the largest difference in absolute vertical positions is about 1.3 m. Table 3-3 shows that the RSM relative CE and LE are about 0.3 m and 0.6 m, which are also in excellent agreement between original and RSM calculations. The RMS relative horizontal and vertical solution differences are about 0.3 m and 0.4 m, respectively. The largest relative horizontal and vertical solution differences for any of the 990 pairs of tie points are about 1.4 m and 1.9 m, respectively.

The RSM performance in the Replace/Triangulate scenario is an example of RSM performing well even outside of the envelope for which it was designed. RSM is designed to provide adjustability virtually equivalent to the adjustability of the original sensor model as long as the change in the model's operating point doesn't have too large of an effect on the sensor model partial derivatives, typically at the 1 % level. In this study, adjustments on the order of the 30 m sensor position uncertainty and 0.05 rad attitude uncertainty at a range of 600 m affect the sensor model partial derivatives at about the 5 % level. The second part of this study, presented below, examines the improvement in RSM adjustability performance when its second operating assumption is met.

As expected, the results for the final scenario, Replace/Triangulate/Extract, are comparable to the results of the Replace/Triangulate scenario. When the last two lines of Table 3-2 and Table 3-3 (Replace/Triangulate/Extract scenario) are compared with the two lines just above them (Replace/Triangulate scenario), the main difference noted is that the maximum statistics are larger in the Replace/Triangulate scenario, because there are more points in the sample from which the maxima are taken.

Table 3-4 and Table 3-5 show the detailed "ground truth" check point comparisons for the Replace/Triangulate/Extract scenario. For each of the three check points and for both the original and RSM processes, the absolute and relative differences between the surveyed positions and the results of the target extraction are well within their 90 % error estimates. Note that the relevant error estimates in this case are the square roots of the sums of the squares (RSS) of the survey error estimates and the extraction error estimates. In most cases the RSM differences from the surveyed coordinates are a little larger than the original sensor model differences from the surveyed coordinates. The three cases in which the reverse is true are simply a result of good fortune, since the RSM support data are fit to the original sensor model and the RSM extraction is intended to match the original sensor model extraction, and no survey information is made available to the RSM Generator.

In the following Table 3-4, the reference (Ref) is the surveyed check point. No equality is expected between the comparison CE or LE (obtained from target extraction) and the reference CE or LE (obtained from the ground survey). The horizontal and vertical differences are with respect to the surveyed check points, and are not differences between original sensor model and RSM extractions. The horizontal differences should be considered in the context of the square root of the sum of the squares (RSS) of the reference and comparison CEs, and similarly the vertical differences should be considered in the context of the RSS of the reference and comparison LEs.

Table 3-4: Nadir Replace/Triangulate/Extract Check Point Absolute Geopositioning Comparisons

POINT ID	Comparison	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
PH12	Original	0.215	0.231	0.493	0.517	0.051	-0.112
	RSM		0.231		0.517	0.156	-0.104
CHEM	Original	0.215	0.158	0.493	0.337	0.020	-0.198
	RSM		0.158		0.334	0.082	-0.075
MACK	Original	0.644	0.241	0.822	0.459	0.076	-0.044
	RSM		0.241		0.453	0.134	-0.462
RMS	Original	0.411	0.213	0.623	0.444	0.054	0.134
	RSM		0.213		0.441	0.128	0.277

In the absence of any information about the relative uncertainties of the check points, Table 3-5 shows that the reference relative CE and LE have been taken to be zero, as if there were perfect positive correlation of ground survey errors between the points.

Table 3-5: Nadir Replace/Triangulate/Extract Check Point Relative Geopositioning Comparisons

POINT ID	POINT ID	Comparison	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
PH12	CHEM	Original	0.000	0.197	0.000	0.458	0.071	-0.086
		RSM		0.197		0.457	0.136	0.029
PH12	MACK	Original	0.000	0.299	0.000	0.661	0.050	0.068
		RSM		0.299		0.646	0.285	-0.358
MACK	MACK	Original	0.000	0.229	0.000	0.450	0.092	0.154
		RSM		0.230		0.439	0.203	-0.387
RMS (check point pair)		Original	0.000	0.246	0.000	0.532	0.073	0.109
		RSM		0.246		0.522	0.217	0.305

3.2.2Results Using Modified *A Priori* Support Data

In order to verify that the accuracy of the RSM performance for triangulation in the study results above is limited primarily by the large change in the sensor model operating point in the triangulation, an experiment was performed as an excursion. The Replace/Triangulate and the Replace/Triangulate/Extract experiments were repeated using modified original *a priori* image support data. First, the original frame sensor models are triangulated with all of the control and tie points. Then, perturbations of the sensor positions and attitudes are randomly generated independently for all 12 images. The perturbations are consistent with support data errors of 8 m (one standard deviation) for position and 0.01 rad (one standard deviation) for attitude euler angles. With error estimates of this size, the changes in the sensor model partial derivatives in adjustment are expected to be around the 1 % level, near the edge but not outside of the expected triangulation optimal performance envelope for RSM.

With the triangulated/perturbed *a priori* support data, the last two scenarios were repeated. The statistics of the comparisons of the original sensor model and RSM performance are shown in Table 3-6 and Table 3-7. As expected, the absolute and relative horizontal and vertical differences between original and RSM tie point positions have become smaller in this excursion study than with the baseline *a priori* support data. The table shows that the RMS differences are now well under 0.1 m. Recall that the GSDs of the images are about 0.11 m. The RSM solution differences, and even the maximum differences, are well below the 90 % error estimates, confirming that the RSM performance is virtually the same in the adjustment as for the original sensor model.

Table 3-6: Perturbed Absolute Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Triangulate	RMS	0.255	0.255	0.496	0.496	0.047	0.059
	max	0.539	0.540	0.850	0.850	0.127	0.175
Replace/Triangulate /Extract	RMS	0.213	0.213	0.442	0.440	0.035	0.050
	max	0.241	0.240	0.514	0.510	0.049	0.065

Table 3-7: Perturbed Relative Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Triangulate	RMS	0.302	0.302	0.567	0.567	0.058	0.083
	max	0.724	0.722	1.257	1.263	0.219	0.301
Replace/Triangulate /Extract	RMS	0.246	0.245	0.527	0.523	0.031	0.086
	max	0.299	0.299	0.655	0.648	0.043	0.110

3.3Oblique Geometry Test Case and Results

The large-FOV frame test case is already challenging for RSM because of the large change in imaging geometry across the field of view. The test images are nadir-looking, but because of the wide field-of-view some of the imaging rays are inclined at forty degrees or more from nadir. A second excursion study was done to make the imaging geometry even more challenging. In the excursion, the study images were used as a basis for the simulation of more highly oblique images, while still keeping large fields of view. The obliquity was increased to the point where every image includes the horizon.

The simulation of the oblique test case begins with the triangulation of the nadir-looking original frame sensor models. The ground coordinates of all of the points after this initial triangulation are used as "truth" in the oblique case.

Next, a nominal azimuth angle and a nominal elevation angle are chosen for the oblique images. The same two angles are used for all twelve images. For this experiment, the azimuth angle was chosen to be 90 degrees, so that the sensor positions are moved eastward from their nadir-looking positions, and the elevation angle was chosen to be 30 degrees, so that the imaging geometry is highly oblique as shown in Figure 3-6. For each image, a new sensor position and attitude are found such the range for the oblique image is the same as for the corresponding nadir image, and so that the oblique image is centered on the same ground coordinates as the corresponding nadir image. The new sensor position and attitude are considered the "true" oblique image support data. The details of the simulated oblique imaging geometry are given in the Appendix in Table A.3 - .

With the simulated oblique sensor geometry for the 12 images, the "true" ground coordinates (obtained from triangulation of the nadir images as described above) are used to compute the corresponding "true" image coordinates for every image/ground point combination that had a measurement in the nadir case. The "true" image coordinates are then perturbed by randomly generated errors, normally distributed with a 1-standard-deviation error of 0.5 pixels. The perturbed measurements are stored for use in the oblique case for both the original sensor model and the RSM tests.

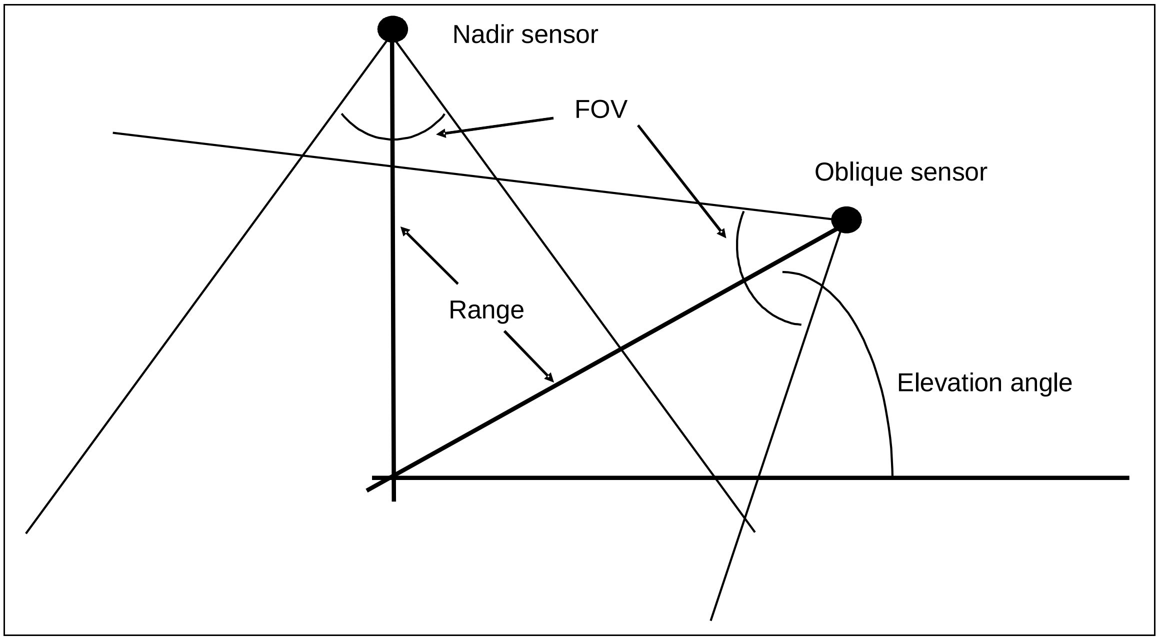

Figure 3-6: Nadir vs Oblique Imaging Geometry.

Once the "true" ground coordinates and "true" oblique support data have been used to compute the "true" image coordinates, and the latter have been perturbed for the purposes of experimentation, additional perturbations are generated for the experiments. First, perturbations are generated for the ground points. The amounts of the perturbations are consistent with a normal distribution with a 1-standard-deviation error of 0.1 m in each horizontal component and 0.3 m in the vertical component. Even though the coordinates of all of the ground points are perturbed, it is only for the three points used as ground control that the ground point perturbations affect the experiments.

Finally, perturbations are generated for the sensor position and attitude. The sensor position perturbations are consistent with a normal distribution with a 1-standard-deviation error of 8 m, and the attitude perturbations are consistent with a normal distribution with a 1-standard-deviation error of 0.01 rad (0.57 deg). The attitude errors correspond to about 8 m at the nominal range. The perturbed oblique image support data are used for the original sensor model experiments, and are used for generating the RSM support data. As with the excursion test for the nadir case above, the support data uncertainties are near the edge, but not outside, the expected triangulation optimal performance envelope for RSM.

The RSM projective model generation proceeds as in the nadir case, with the RSM Generator automatically selecting a linear rational polynomial in a local east-north-up rectangular coordinate system specific to each image. With the combination of large FOV and highly oblique image geometry, some of the image rows are directed above the horizon. In these cases, the RSM Generator automatically detects the failure of the original image-to-ground function and narrows the RSM image domain to a region in which there are no original sensor model errors. This is true when the top of the image is above the horizon (in which case the RSM Generator eliminates rows at the top of the image), and when the image is rotated so that the bottom of the image is above the horizon (in which case the RSM Generator eliminates rows at the bottom of the image); both types of cases arose in the study. As with the nadir images, the projective model fitting errors are well below 0.001 pixels.

As with the nadir images, the RSM Generator automatically selects ground-space translation (in three dimensions) and small-angle rotations about three orthogonal axes as the adjustable parameters, for a total of six RSM adjustable parameters, and finds a good mapping of the original to RSM error covariance.

When the simulated oblique sensor models are triangulated, an inspection of the triangulation log for the original sensor model shows that the adjustments are comparable with the simulated adjustable parameter uncertainties as expected (8 m one-standard deviation for sensor position, 0.01 rad one-standard deviation for attitude). This gives confidence that the simulation was developed correctly.

The absolute and relative geopositioning statistics for the simulated oblique images are shown in Table 3-8 and Table 3-9 below. Both the Replace/Triangulate and the Replace/Triangulate/Extract results are shown, and they are similar to each other. The CE and LE estimates differ by less than two percent between original sensor model and RSM operations. The RMS horizontal and vertical solution differences are around 0.1 m or less.

Table 3-8: Oblique Absolute Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Triangulate	RMS	0.446	0.447	0.405	0.406	0.099	0.042
	max	1.150	1.152	0.657	0.660	0.230	0.077
Replace/Triangulate /Extract	RMS	0.382	0.383	0.377	0.378	0.100	0.046
	max	0.534	0.535	0.409	0.410	0.112	0.057

Table 3-9: Oblique Relative Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Triangulate	RMS	0.556	0.557	0.444	0.445	0.108	0.033
	max	1.455	1.457	0.971	0.983	0.421	0.128
Replace/Triangulate /Extract	RMS	0.469	0.470	0.449	0.451	0.061	0.016
	max	0.556	0.557	0.552	0.555	0.084	0.022

4.0Conclusions

All aspects of RSM performance were successfully verified for a large format frame camera using real imagery and image support data. The test scenario was challenging in that the sensor platform altitude was low and the sensor field-of-view large.

In particular, RSM extraction, accuracy prediction, and adjustments all matched their original sensor model counterparts to within approximately 0.001 pixels, 0.1 meters, and 0.1 meters, respectively.

The above adjustability results (only) required that the RSM operational constraint regarding support data uncertainty was satisfied. In particular, that pre-adjustment sensor model uncertainty was compatible with a 1 % change or less to appropriate partial derivatives due to sensor model adjustment. Changes at the 5% level still provided reasonable comparisons between RSM triangulation and its original sensor model counterpart, but not virtually identical comparisons.

In addition, the overall test was expanded to address high oblique images that include the horizon. The baseline image support data was modified in order to simulate the high oblique images. RSM performance was successfully verified for this scenario as well.

5.0Acknowledgements

We would like to take this opportunity to thank the National Geospatial-Intelligence Agency (NGA) for this performance sub-study of the RSM Tactical Imagery Study Phase 4 charter and for their support during the preparation of this paper as a part of JTW contract # NMA201-01-C-0028.

6.0References

The following are general references for the Replacement Sensor Model:

(1) RSM Tagged Record Extension (TRE) Specification, NTB public web pages, http://www.gwg.nga.mil/ntb/index.html.

(2) Dolloff, John. "Replacement Sensor Models", Chapter 11.3, Manual of Photogrammetry, 5th Edition, J. Chris McGlone editor, ASPRS, 2004.

(3) Iiyama, Michelle, J. Dolloff, and C. Taylor. "The ABC's of RSM: An introduction to the Replacement Sensor Model", September 30, 2006. Available via : BAE Systems Geospatial eXploitation (Special) Products: http://socetset.com/products/products_git.htm

Appendix A

A.1Nadir Test Results Using Baseline *A Priori* Support Data

Table A.1 - : Nadir Imaging Geometry Detail

Image	1	2	3	4	5	6	7	8	9	10	11	12
Image ID	'1_6'	'1_7'	'1_8'	'1_9'	'2_4'	'2_5'	'2_6'	'2_7'	'3_5'	'3_6'	'3_7'	'3_8'
Number of rows	7776	7840	7904	7840	7840	7776	7872	7840	7776	7840	7840	7936
Number of columns	7712	7776	7840	7776	7776	7712	7808	7776	7712	7776	7776	7872
Ground reference height (m)	214	211	204	196	198	204	205	205	226	222	217	213
Image azimuth angle of north (rad)	-3.068	-3.075	-3.075	-3.061	-3.060	-3.068	-3.081	-3.059	-3.068	-3.059	-3.074	-3.048
Image azimuth angle of up (rad)	0.073	0.067	0.067	0.081	0.082	0.074	0.061	0.083	0.073	0.083	0.067	0.093
Row GSD (LOS-normal) (m)	0.115	0.115	0.116	0.118	0.118	0.116	0.116	0.116	0.112	0.113	0.114	0.115
Column GSD (LOS-normal) (m)	0.115	0.115	0.116	0.118	0.118	0.116	0.116	0.116	0.112	0.113	0.114	0.115
Azimuth angle of imaging locus (rad)	-1.932	-2.350	-2.349	-2.329	-2.344	-2.120	-2.110	-2.345	-2.252	-2.345	-2.307	-2.346
Elevation angle of imaging locus (rad)	1.570	1.568	1.568	1.567	1.568	1.570	1.570	1.569	1.570	1.569	1.567	1.567
Nominal sensor height (m)	800	800	800	800	800	800	800	800	800	800	800	800
Nominal range (m)	586	589	596	604	602	596	595	595	574	578	583	587
Row IFOV (per pixel) (mrad)	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196
Column IFOV (per pixel) (mrad)	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196
Row FOV (full image) (rad)	1.525	1.537	1.550	1.537	1.537	1.525	1.543	1.537	1.524	1.537	1.537	1.556
Column FOV (full image) (rad)	1.512	1.524	1.537	1.524	1.524	1.512	1.531	1.524	1.512	1.525	1.525	1.543

The following tables contain columns denoting percent differences. "CE diff %" is the difference between the comparison CE and the reference CE, all divided by the reference CE, expressed as a percentage. Likewise the "LE diff %" is the difference between the comparison LE and the reference LE, all divided by the reference LE, expressed as a percentage. The "Horiz diff" is the distance from the target's horizontal position as determined in the reference situation to the target's horizontal position as determined in the comparison situation, and the Horiz diff % is the "Horiz diff" divided by the reference CE, expressed as a percentage. The "Vert diff" is the offset of the height obtained in reference situation with respect to the height obtained in the comparison situation, and the "Vert diff %" is the "Vert diff" divided by the reference LE, expressed as a percentage.

Table A.1 - : Nadir Replace/Extract RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	38.092	38.047	-0.119	61.827	61.784	-0.069	0.054	0.073	0.142	0.117
CHEM	check	77.924	77.906	-0.023	183.982	184.117	0.073	0.025	-0.049	0.032	-0.027
MACK	check	97.118	97.096	-0.023	161.924	161.970	0.028	0.114	0.220	0.117	0.136
Mean (check point)		71.044	71.016	0.055	135.911	135.957	0.057	0.064	0.114	0.097	0.093
Max (check point)		97.118	97.096	0.119	183.982	184.117	0.073	0.114	0.220	0.142	0.136
Max2 (check point)		77.924	77.906	0.023	161.924	161.970	0.069	0.054	0.073	0.117	0.117
RMS (check point)		75.178	75.154	0.071	145.935	146.003	0.060	0.074	0.137	0.108	0.105

Table A.1 - : Nadir Replace/Extract RSM (Comp) vs. Original Frame (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	86.428	86.393	-0.041	194.093	194.207	0.059	0.029	-0.122	0.034	-0.063
PH12	MACK	96.971	96.922	-0.050	185.737	185.841	0.056	0.158	0.148	0.163	0.079
CHEM	MACK	123.962	123.931	-0.025	245.089	245.220	0.054	0.134	0.270	0.108	0.110
Mean (check point pair)		102.453	102.415	0.039	208.306	208.423	0.056	0.107	0.180	0.102	0.084
Max (check point pair)		123.962	123.931	0.050	245.089	245.220	0.059	0.158	0.270	0.163	0.110
Max2 (check point pair)		96.971	96.922	0.041	194.093	194.207	0.056	0.134	0.148	0.108	0.079
RMS (check point pair)		103.666	103.628	0.040	209.951	210.068	0.056	0.121	0.191	0.115	0.086

Table A.1 - : Nadir Replace/Extract Original Frame (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.215	77.924	0.493	183.982	26.360	9.023	33.827	4.904
CHEM	check	0.215	38.092	0.493	61.827	9.568	12.001	25.117	19.410
MACK	check	0.644	97.118	0.822	161.924	7.265	8.625	7.481	5.327
Mean (check point)		0.358	71.044	0.603	135.911	14.397	9.883	22.142	9.880
Max (check point)		0.644	97.118	0.822	183.982	26.360	12.001	33.827	19.410
Max2 (check point)		0.215	77.924	0.493	161.924	9.568	9.023	25.117	5.327
RMS (check point)		0.411	75.178	0.623	145.935	16.725	9.997	24.706	11.961

Table A.1 - : Nadir Replace/Extract Original Frame (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	86.428	0.000	194.093	19.514	2.978	22.578	1.535
PH12	MACK	0.000	123.962	0.000	245.089	33.390	-0.398	26.936	-0.162
CHEM	MACK	0.000	96.971	0.000	185.737	16.582	-3.376	17.099	-1.818
Mean (check point pair)		0.000	102.453	0.000	208.306	23.162	2.251	22.205	1.171
Max (check point pair)		0.000	123.962	0.000	245.089	33.390	3.376	26.936	1.818
Max2 (check point pair)		0.000	96.971	0.000	194.093	19.514	2.978	22.578	1.535
RMS (check point pair)		0.000	103.666	0.000	209.951	24.294	2.609	22.566	1.377

Table A.1 - : Nadir Replace/Extract RSM (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.215	77.906	0.493	184.117	26.343	8.973	33.814	4.874
CHEM	check	0.215	38.047	0.493	61.784	9.515	12.074	25.008	19.541
MACK	check	0.644	97.096	0.822	161.970	7.153	8.845	7.367	5.461
Mean (check point)		0.358	71.016	0.603	135.957	14.337	9.964	22.063	9.959
Max (check point)		0.644	97.096	0.822	184.117	26.343	12.074	33.814	19.541
Max2 (check point)		0.215	77.906	0.493	161.970	9.515	8.973	25.008	5.461
RMS (check point)		0.411	75.154	0.623	146.003	16.690	10.075	24.651	12.048

Table A.1 - : Nadir Replace/Extract RSM (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	86.393	0.000	194.207	19.525	3.101	22.601	1.597
PH12	MACK	0.000	123.931	0.000	245.220	33.259	-0.128	26.837	-0.052
CHEM	MACK	0.000	96.922	0.000	185.841	16.425	-3.229	16.946	-1.737
Mean (check point pair)		0.000	102.415	0.000	208.423	23.070	2.152	22.128	1.129
Max (check point pair)		0.000	123.931	0.000	245.220	33.259	3.229	26.837	1.737
Max2 (check point pair)		0.000	96.922	0.000	194.207	19.525	3.101	22.601	1.597
RMS (check point pair)		0.000	103.628	0.000	210.068	24.202	2.585	22.496	1.363

Table A.1 - : Nadir Triangulate/Replace/Extract RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.158	0.158	-0.126	0.337	0.333	-1.159	0.000	0.001	0.127	0.208
CHEM	check	0.231	0.231	-0.043	0.517	0.513	-0.793	0.000	-0.001	0.117	-0.271
MACK	check	0.241	0.241	0.000	0.459	0.457	-0.392	0.000	0.001	0.075	0.261
Mean (check point)		0.210	0.210	0.057	0.438	0.434	0.781	0.000	0.001	0.106	0.247
Max (check point)		0.241	0.241	0.126	0.517	0.513	1.159	0.000	0.001	0.127	0.271
Max2 (check point)		0.231	0.231	0.043	0.459	0.457	0.793	0.000	0.001	0.117	0.261
RMS (check point)		0.213	0.213	0.077	0.444	0.441	0.842	0.000	0.001	0.108	0.248

Table A.1 - : Nadir Triangulate/Replace/Extract RSM (Comp) vs. Original Frame (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.197	0.197	-0.051	0.458	0.455	-0.612	0.000	-0.002	0.065	-0.459
PH12	MACK	0.229	0.229	0.000	0.450	0.449	-0.089	0.000	0.000	0.039	0.111
CHEM	MACK	0.299	0.299	0.000	0.661	0.660	-0.091	0.000	0.003	0.030	0.393
Mean (check point pair)		0.242	0.242	0.017	0.523	0.521	0.264	0.000	0.002	0.045	0.321
Max (check point pair)		0.299	0.299	0.051	0.661	0.660	0.612	0.000	0.003	0.065	0.459
Max2 (check point pair)		0.229	0.229	0.000	0.458	0.455	0.091	0.000	0.002	0.039	0.393
RMS (check point pair)		0.246	0.246	0.029	0.532	0.531	0.361	0.000	0.002	0.047	0.355

Table A.1 - : Nadir Triangulate/Replace/Extract Original Frame (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.215	0.231	0.493	0.517	0.051	-0.112	16.045	-15.680
CHEM	check	0.215	0.158	0.493	0.337	0.020	-0.198	7.617	-33.149
MACK	check	0.644	0.241	0.822	0.459	0.076	-0.044	10.998	-4.651
Mean (check point)		0.358	0.210	0.603	0.438	0.049	0.118	11.553	17.826
Max (check point)		0.644	0.241	0.822	0.517	0.076	0.198	16.045	33.149
Max2 (check point)		0.215	0.231	0.493	0.459	0.051	0.112	10.998	15.680
RMS (check point)		0.411	0.213	0.623	0.444	0.054	0.134	12.061	21.341

Table A.1 - : Nadir Triangulate/Replace/Extract Original Frame (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.197	0.000	0.458	0.071	-0.086	35.963	-18.768
PH12	MACK	0.000	0.299	0.000	0.661	0.050	0.068	16.816	10.336
CHEM	MACK	0.000	0.229	0.000	0.450	0.092	0.154	39.994	34.305
Mean (check point pair)		0.000	0.242	0.000	0.523	0.071	0.103	30.924	21.136
Max (check point pair)		0.000	0.299	0.000	0.661	0.092	0.154	39.994	34.305
Max2 (check point pair)		0.000	0.229	0.000	0.458	0.071	0.086	35.963	18.768
RMS (check point pair)		0.000	0.246	0.000	0.532	0.073	0.109	32.535	23.352

Table A.1 - : Nadir Triangulate/Replace/Extract RSM (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.215	0.231	0.493	0.513	0.051	-0.113	16.125	-15.941
CHEM	check	0.215	0.158	0.493	0.333	0.020	-0.197	7.574	-33.153
MACK	check	0.644	0.241	0.822	0.457	0.076	-0.043	11.008	-4.527
Mean (check point)		0.358	0.210	0.603	0.434	0.049	0.118	11.569	17.874
Max (check point)		0.644	0.241	0.822	0.513	0.076	0.197	16.125	33.153
Max2 (check point)		0.215	0.231	0.493	0.457	0.051	0.113	11.008	15.941
RMS (check point)		0.411	0.213	0.623	0.441	0.054	0.134	12.091	21.399

Table A.1 - : Nadir Triangulate/Replace/Extract RSM (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.197	0.000	0.455	0.071	-0.084	36.042	-18.422
PH12	MACK	0.000	0.299	0.000	0.660	0.050	0.071	16.826	10.739
CHEM	MACK	0.000	0.229	0.000	0.449	0.092	0.155	40.027	34.447
Mean (check point pair)		0.000	0.242	0.000	0.521	0.071	0.103	30.965	21.202
Max (check point pair)		0.000	0.299	0.000	0.660	0.092	0.155	40.027	34.447
Max2 (check point pair)		0.000	0.229	0.000	0.455	0.071	0.084	36.042	18.422
RMS (check point pair)		0.000	0.246	0.000	0.531	0.073	0.110	32.580	23.390

Table A.1 - : Nadir Replace/Triangulate RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
HISC	control	0.191	0.190	-0.105	0.410	0.406	-1.072	0.030	0.153	15.702	37.217
PH11	control	0.182	0.182	0.000	0.428	0.427	-0.257	0.016	-0.019	8.615	-4.463
LILY	control	0.202	0.201	-0.099	0.449	0.445	-0.824	0.004	-0.013	1.957	-2.986
BBLL	control	0.183	0.182	-0.164	0.425	0.421	-0.847	0.047	0.179	25.983	42.084
STNE	control	0.183	0.184	0.273	0.402	0.396	-1.518	0.063	-0.299	34.199	-74.316
p1_7	tie	0.349	0.348	-0.258	0.699	0.707	1.101	0.165	0.482	47.247	68.869
p1_6	tie	0.252	0.251	-0.119	0.552	0.549	-0.562	0.021	0.187	8.370	33.829
p2_8	tie	0.271	0.271	0.222	0.541	0.531	-1.775	0.047	0.048	17.515	8.819
p2_7	tie	0.184	0.185	0.109	0.406	0.401	-1.011	0.079	0.015	42.706	3.650
p2_6	tie	0.165	0.165	-0.121	0.359	0.357	-0.696	0.080	0.086	48.506	23.886
p3_6	tie	0.172	0.172	-0.174	0.357	0.355	-0.616	0.079	0.127	45.917	35.610
p3_5	tie	0.149	0.149	-0.335	0.323	0.321	-0.465	0.060	0.152	40.018	47.104
p1_5	tie	0.258	0.258	-0.039	0.560	0.553	-1.215	0.054	0.142	20.988	25.415
p2_5	tie	0.164	0.164	-0.122	0.358	0.355	-0.726	0.091	0.136	55.165	37.933
p1_4	tie	0.289	0.289	0.069	0.593	0.581	-1.890	0.077	0.095	26.652	16.115
p2_4	tie	0.178	0.178	-0.056	0.390	0.387	-0.897	0.078	0.241	43.982	61.718
p3_4	tie	0.160	0.159	-0.502	0.348	0.346	-0.746	0.103	0.243	64.534	69.747
p1_3	tie	0.473	0.473	0.085	0.802	0.790	-1.521	0.384	-0.386	81.319	-48.062
p3_3	tie	0.181	0.180	-0.552	0.389	0.385	-1.157	0.156	0.291	86.268	74.781
p2_2	tie	0.275	0.274	-0.036	0.559	0.551	-1.396	0.351	0.584	127.761	104.420
p3_7	tie	0.240	0.240	-0.083	0.448	0.443	-1.116	0.098	-0.352	41.008	-78.460
p4_7	tie	0.177	0.177	-0.225	0.398	0.398	0.000	0.099	-0.022	55.761	-5.528

p4_5	tie	0.165	0.165	-0.544	0.352	0.353	0.170	0.119	0.167	71.828	47.388
p4_4	tie	0.169	0.169	-0.296	0.378	0.378	0.132	0.151	0.177	89.448	46.732
p4_3	tie	0.198	0.197	-0.203	0.436	0.435	-0.275	0.149	0.081	75.663	18.474
p4_2	tie	0.247	0.247	0.000	0.524	0.521	-0.516	0.235	-0.008	95.242	-1.528
p5_4	tie	0.269	0.268	-0.223	0.559	0.558	-0.286	0.159	-0.129	59.171	-23.100
p5_3	tie	0.491	0.489	-0.367	0.803	0.804	0.037	0.603	-0.260	122.900	-32.329
p5_5	tie	0.214	0.214	-0.327	0.465	0.464	-0.387	0.148	-0.001	69.248	-0.236
p5_6	tie	0.241	0.242	0.290	0.511	0.513	0.490	0.063	-0.217	26.194	-42.491
p5_7	tie	0.539	0.537	-0.519	0.852	0.843	-1.091	0.999	-1.268	185.107	-148.762
cary	tie	0.151	0.150	-0.331	0.330	0.329	-0.394	0.052	0.088	34.682	26.749
sand	tie	0.176	0.175	-0.114	0.383	0.379	-0.889	0.085	0.233	48.151	60.951
owen	tie	0.170	0.170	-0.059	0.372	0.370	-0.618	0.067	0.040	39.313	10.687
tark	tie	0.179	0.179	-0.056	0.373	0.372	-0.402	0.056	0.036	31.382	9.753
T19	tie	0.157	0.156	-0.511	0.342	0.342	-0.058	0.074	0.084	46.939	24.511
t19_tie	tie	0.156	0.155	-0.513	0.339	0.339	0.029	0.067	0.095	43.206	27.956
solon	tie	0.181	0.180	-0.221	0.413	0.412	-0.242	0.096	-0.008	53.306	-1.984
p4_6	tie	0.173	0.172	-0.347	0.383	0.383	0.131	0.123	0.097	71.368	25.301
COREC	tie	0.265	0.265	-0.075	0.476	0.474	-0.462	0.034	0.349	12.850	73.263
LAMBERT	tie	0.188	0.187	-0.425	0.392	0.393	0.179	0.049	0.069	25.822	17.551
schl	tie	0.170	0.169	-0.295	0.382	0.383	0.288	0.114	0.155	67.473	40.713
PSYCHO	tie	0.313	0.314	0.128	0.640	0.641	0.234	0.268	0.376	85.397	58.856
PU_MALL01	tie	0.451	0.451	-0.022	0.739	0.741	0.216	0.341	0.402	75.652	54.368
MSEE	tie	0.245	0.244	-0.409	0.569	0.565	-0.808	0.137	0.138	55.978	24.284
Mean (tie point)		0.236	0.236	0.235	0.477	0.475	0.631	0.155	0.202	58.501	39.048
Max (tie point)		0.539	0.537	0.552	0.852	0.843	1.890	0.999	1.268	185.107	148.762
Max2 (tie point)		0.491	0.489	0.544	0.803	0.804	1.775	0.603	0.584	127.761	104.420
RMS (tie point)		0.256	0.255	0.287	0.498	0.496	0.795	0.235	0.298	67.427	49.331

Table A.1 - : Nadir Replace/Triangulate RSM (Comp) vs. Original Frame (Ref) Relative*

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
Mean (tie point pair)		0.271	0.271	0.200	0.527	0.523	1.055	0.208	0.275	64.256	47.875
Max (tie point pair)		0.725	0.725	0.803	1.264	1.238	3.873	1.370	1.851	217.611	190.707
Max2 (tie point pair)		0.676	0.672	0.802	1.146	1.157	3.785	1.223	1.749	216.964	182.261
RMS (tie point pair)		0.302	0.302	0.255	0.570	0.566	1.297	0.326	0.415	78.960	61.517

*Detailed listing of 990 lines omitted for brevity.

Table A.1 - : Nadir Replace/Triangulate/Extract RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.158	0.158	-0.316	0.337	0.334	-0.713	0.067	0.123	42.632	36.553
CHEM	check	0.231	0.231	-0.043	0.517	0.517	-0.097	0.155	0.008	67.046	1.488
MACK	check	0.241	0.241	-0.207	0.459	0.453	-1.264	0.088	-0.419	36.310	-91.198
Mean (check point)		0.210	0.210	0.189	0.438	0.435	0.691	0.103	0.183	48.663	43.080
Max (check point)		0.241	0.241	0.316	0.517	0.517	1.264	0.155	0.419	67.046	91.198
Max2 (check point)		0.231	0.231	0.207	0.459	0.453	0.713	0.088	0.123	42.632	36.553
RMS (check point)		0.213	0.213	0.220	0.444	0.441	0.840	0.110	0.252	50.435	56.732

Table A.1 - : Nadir Replace/Triangulate/Extract RSM (Comp) vs. Original Frame (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.197	0.197	-0.203	0.458	0.457	-0.197	0.103	-0.115	52.310	-25.191
PH12	MACK	0.229	0.230	0.393	0.450	0.439	-2.291	0.134	-0.542	58.471	-120.489
CHEM	MACK	0.299	0.299	0.067	0.661	0.646	-2.225	0.235	-0.426	78.536	-64.513
Mean (check point pair)		0.242	0.242	0.221	0.523	0.514	1.571	0.157	0.361	63.106	70.064
Max (check point pair)		0.299	0.299	0.393	0.661	0.646	2.291	0.235	0.542	78.536	120.489
Max2 (check point pair)		0.229	0.230	0.203	0.458	0.457	2.225	0.134	0.426	58.471	64.513
RMS (check point pair)		0.246	0.246	0.258	0.532	0.522	1.847	0.167	0.403	64.092	80.238

Table A.1 - : Nadir Replace/Triangulate/Extract Original Frame (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %

PH12	check	0.215	0.231	0.493	0.517	0.051	-0.112	16.045	-15.680
CHEM	check	0.215	0.158	0.493	0.337	0.020	-0.198	7.617	-33.149
MACK	check	0.644	0.241	0.822	0.459	0.076	-0.044	10.998	-4.651
Mean (check point)		0.358	0.210	0.603	0.438	0.049	0.118	11.553	17.826
Max (check point)		0.644	0.241	0.822	0.517	0.076	0.198	16.045	33.149
Max2 (check point)		0.215	0.231	0.493	0.459	0.051	0.112	10.998	15.680
RMS (check point)		0.411	0.213	0.623	0.444	0.054	0.134	12.061	21.341

Table A.1 - : Nadir Replace/Triangulate/Extract Original Frame (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.197	0.000	0.458	0.071	-0.086	35.963	-18.768
PH12	MACK	0.000	0.299	0.000	0.661	0.050	0.068	16.816	10.336
CHEM	MACK	0.000	0.229	0.000	0.450	0.092	0.154	39.994	34.305
Mean (check point pair)		0.000	0.242	0.000	0.523	0.071	0.103	30.924	21.136
Max (check point pair)		0.000	0.299	0.000	0.661	0.092	0.154	39.994	34.305
Max2 (check point pair)		0.000	0.229	0.000	0.458	0.071	0.086	35.963	18.768
RMS (check point pair)		0.000	0.246	0.000	0.532	0.073	0.109	32.535	23.352

Table A.1 - : Nadir Replace/Triangulate/Extract RSM (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.215	0.231	0.493	0.517	0.156	-0.104	49.318	-14.610
CHEM	check	0.215	0.158	0.493	0.334	0.082	-0.075	30.689	-12.585
MACK	check	0.644	0.241	0.822	0.453	0.134	-0.462	19.496	-49.244
Mean (check point)		0.358	0.210	0.603	0.435	0.124	0.214	33.168	25.479
Max (check point)		0.644	0.241	0.822	0.517	0.156	0.462	49.318	49.244
Max2 (check point)		0.215	0.231	0.493	0.453	0.134	0.104	30.689	14.610
RMS (check point)		0.411	0.213	0.623	0.441	0.128	0.277	35.375	30.533

Table A.1 - : Nadir Replace/Triangulate/Extract RSM (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.197	0.000	0.457	0.136	0.029	69.008	6.436

PH12	MACK	0.000	0.299	0.000	0.646	0.285	-0.358	95.126	-55.409
CHEM	MACK	0.000	0.230	0.000	0.439	0.203	-0.387	88.432	-88.206
Mean (check point pair)		0.000	0.242	0.000	0.514	0.208	0.258	84.189	50.017
Max (check point pair)		0.000	0.299	0.000	0.646	0.285	0.387	95.126	88.206
Max2 (check point pair)		0.000	0.230	0.000	0.457	0.203	0.358	88.432	55.409
RMS (check point pair)		0.000	0.246	0.000	0.522	0.217	0.305	84.914	60.255

A.2Nadir Triangulation Results Using Modified *A Priori* Support Data

Table A.2 - : Perturbed Replace/Triangulate RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
HISC	control	0.191	0.190	-0.052	0.409	0.408	-0.342	0.007	-0.018	3.864	-4.350
PH11	control	0.182	0.182	0.000	0.425	0.423	-0.541	0.007	-0.008	3.895	-1.906
LILY	control	0.201	0.201	0.000	0.447	0.447	-0.067	0.005	-0.027	2.246	-5.993
BBLL	control	0.182	0.182	-0.110	0.422	0.423	0.142	0.014	-0.015	7.662	-3.598
STNE	control	0.183	0.183	-0.109	0.400	0.399	-0.275	0.014	0.068	7.867	16.908
p1_7	tie	0.348	0.348	-0.029	0.696	0.701	0.675	0.040	0.091	11.421	13.075
p1_6	tie	0.251	0.251	-0.119	0.548	0.550	0.383	0.029	-0.019	11.695	-3.429
p2_8	tie	0.270	0.270	-0.037	0.537	0.534	-0.428	0.046	0.126	16.837	23.566
p2_7	tie	0.184	0.184	-0.217	0.403	0.403	-0.099	0.014	0.053	7.860	13.170
p2_6	tie	0.165	0.164	-0.424	0.358	0.357	-0.028	0.011	-0.005	6.636	-1.286
p3_6	tie	0.172	0.172	-0.406	0.356	0.357	0.253	0.021	0.000	12.374	0.000
p3_5	tie	0.149	0.148	-0.470	0.322	0.323	0.342	0.035	-0.016	23.516	-4.967
p1_5	tie	0.258	0.257	-0.272	0.556	0.559	0.521	0.016	-0.026	6.338	-4.673
p2_5	tie	0.164	0.163	-0.366	0.356	0.357	0.140	0.013	-0.038	8.169	-10.799
p1_4	tie	0.289	0.288	-0.277	0.589	0.593	0.713	0.003	-0.030	1.046	-5.042
p2_4	tie	0.178	0.178	-0.281	0.388	0.389	0.309	0.017	-0.060	9.494	-15.541
p3_4	tie	0.159	0.159	-0.377	0.347	0.348	0.259	0.048	-0.046	30.175	-13.253
p1_3	tie	0.472	0.471	-0.275	0.799	0.805	0.726	0.096	0.053	20.259	6.597
p3_3	tie	0.181	0.180	-0.332	0.387	0.387	0.155	0.061	-0.056	33.969	-14.452
p2_2	tie	0.274	0.272	-0.548	0.555	0.555	0.054	0.093	-0.175	33.964	-31.501
p3_7	tie	0.240	0.239	-0.167	0.446	0.446	-0.022	0.011	0.029	4.467	6.564
p4_7	tie	0.177	0.177	-0.395	0.396	0.397	0.076	0.030	0.047	16.939	11.787
p4_5	tie	0.165	0.164	-0.606	0.351	0.350	-0.285	0.041	0.000	25.119	0.000
p4_4	tie	0.169	0.169	-0.237	0.376	0.374	-0.586	0.045	-0.023	26.753	-6.095
p4_3	tie	0.197	0.197	-0.101	0.433	0.431	-0.554	0.049	-0.046	25.067	-10.598
p4_2	tie	0.247	0.246	-0.122	0.520	0.515	-0.885	0.055	-0.060	22.373	-11.624
p5_4	tie	0.269	0.269	0.074	0.555	0.554	-0.252	0.017	-0.015	6.432	-2.720
p5_3	tie	0.491	0.489	-0.285	0.799	0.797	-0.275	0.127	0.063	25.808	7.922
p5_5	tie	0.214	0.214	-0.140	0.462	0.461	-0.346	0.026	0.021	12.043	4.629

p5_6	tie	0.241	0.241	-0.249	0.508	0.506	-0.374	0.033	0.052	13.857	10.295
p5_7	tie	0.539	0.540	0.111	0.850	0.850	0.082	0.067	0.078	12.376	9.157
cary	tie	0.151	0.150	-0.464	0.329	0.330	0.243	0.032	0.014	21.394	4.253
sand	tie	0.175	0.175	-0.342	0.381	0.382	0.289	0.019	-0.060	10.752	-15.787
owen	tie	0.170	0.169	-0.236	0.371	0.370	-0.135	0.008	0.013	4.621	3.480
tark	tie	0.178	0.178	-0.280	0.372	0.372	-0.054	0.011	0.003	6.227	0.807
T19	tie	0.156	0.156	-0.512	0.341	0.342	0.146	0.037	0.023	23.728	6.827
t19_tie	tie	0.156	0.155	-0.450	0.338	0.338	0.089	0.035	0.024	22.359	7.069
solon	tie	0.181	0.180	-0.332	0.411	0.413	0.316	0.030	0.039	16.777	9.575
p4_6	tie	0.172	0.172	-0.464	0.381	0.381	0.079	0.038	0.024	22.210	6.350
COREC	tie	0.265	0.265	-0.113	0.474	0.475	0.169	0.034	-0.099	12.966	-20.974
LAMBERT	tie	0.188	0.187	-0.319	0.391	0.392	0.102	0.030	0.037	16.009	9.407
schl	tie	0.169	0.169	-0.295	0.380	0.379	-0.289	0.047	-0.031	28.041	-8.261
PSYCHO	tie	0.313	0.313	-0.128	0.637	0.635	-0.376	0.071	-0.091	22.801	-14.275
PU_MALL01	tie	0.450	0.450	-0.044	0.737	0.732	-0.584	0.078	-0.112	17.268	-15.261
MSEE	tie	0.244	0.244	-0.205	0.568	0.568	0.035	0.042	-0.031	17.123	-5.459
Mean (tie point)		0.236	0.235	0.278	0.475	0.475	0.293	0.039	0.046	16.682	9.263
Max (tie point)		0.539	0.540	0.606	0.850	0.850	0.885	0.127	0.175	33.969	31.501
Max2 (tie point)		0.491	0.489	0.548	0.799	0.805	0.726	0.096	0.126	33.964	23.566
RMS (tie point)		0.255	0.255	0.314	0.496	0.496	0.365	0.047	0.059	18.683	11.273

Table A.2 - : Perturbed Replace/Triangulate RSM (Comp) vs. Original Frame (Ref) Relative*

	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
Mean (tie point pair)	0.271	0.271	0.152	0.524	0.524	0.471	0.046	0.066	16.475	13.130
Max (tie point pair)	0.724	0.722	0.679	1.257	1.263	1.410	0.219	0.301	41.213	40.669
Max2 (tie point pair)	0.676	0.675	0.677	1.137	1.138	1.394	0.189	0.266	41.085	39.035
RMS (tie point pair)	0.302	0.302	0.215	0.567	0.567	0.576	0.058	0.083	18.330	15.878

*Detailed listing of 990 lines omitted for brevity.

Table A.2 - : Perturbed Replace/Triangulate/Extract RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.158	0.157	-0.443	0.335	0.336	0.268	0.026	-0.035	16.227	-10.405
CHEM	check	0.231	0.231	-0.087	0.514	0.510	-0.798	0.049	-0.045	21.204	-8.818
MACK	check	0.241	0.240	-0.249	0.457	0.457	0.022	0.024	0.065	9.835	14.173
Mean (check point)		0.210	0.209	0.260	0.435	0.434	0.363	0.033	0.048	15.755	11.132
Max (check point)		0.241	0.240	0.443	0.514	0.510	0.798	0.049	0.065	21.204	14.173
Max2 (check point)		0.231	0.231	0.249	0.457	0.457	0.268	0.026	0.045	16.227	10.405
RMS (check point)		0.213	0.213	0.298	0.442	0.440	0.486	0.035	0.050	16.428	11.357

Table A.2 - : Perturbed Replace/Triangulate/Extract RSM (Comp) vs. Original Frame (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.197	0.197	-0.101	0.454	0.448	-1.322	0.029	-0.010	14.507	-2.291
PH12	MACK	0.229	0.229	0.044	0.447	0.449	0.537	0.015	0.100	6.554	22.324
CHEM	MACK	0.299	0.299	-0.033	0.655	0.648	-1.099	0.043	0.110	14.468	16.809
Mean (check point pair)		0.242	0.242	0.060	0.519	0.515	0.986	0.029	0.073	11.843	13.808
Max (check point pair)		0.299	0.299	0.101	0.655	0.648	1.322	0.043	0.110	14.507	22.324
Max2 (check point pair)		0.229	0.229	0.044	0.454	0.449	1.099	0.029	0.100	14.468	16.809
RMS (check point pair)		0.246	0.245	0.067	0.527	0.523	1.040	0.031	0.086	12.420	16.188

Table A.2 - : Perturbed Replace/Triangulate/Extract Original Frame (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.215	0.231	0.493	0.514	0.057	-0.121	17.958	-17.000
CHEM	check	0.215	0.158	0.493	0.335	0.018	-0.198	6.844	-33.166
MACK	check	0.644	0.241	0.822	0.457	0.078	-0.050	11.337	-5.282
Mean (check point)		0.358	0.210	0.603	0.435	0.051	0.123	12.046	18.483
Max (check point)		0.644	0.241	0.822	0.514	0.078	0.198	17.958	33.166
Max2 (check point)		0.215	0.231	0.493	0.457	0.057	0.121	11.337	17.000
RMS (check point)		0.411	0.213	0.623	0.442	0.057	0.137	12.882	21.733

Table A.2 - : Perturbed Replace/Triangulate/Extract Original Frame (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.197	0.000	0.454	0.075	-0.077	37.817	-16.920
PH12	MACK	0.000	0.299	0.000	0.655	0.048	0.071	16.119	10.901
CHEM	MACK	0.000	0.229	0.000	0.447	0.091	0.148	39.522	33.184
Mean (check point pair)		0.000	0.242	0.000	0.518	0.071	0.099	31.153	20.335
Max (check point pair)		0.000	0.299	0.000	0.655	0.091	0.148	39.522	33.184
Max2 (check point pair)		0.000	0.229	0.000	0.454	0.075	0.077	37.817	16.920
RMS (check point pair)		0.000	0.246	0.000	0.527	0.073	0.105	32.924	22.408

Table A.2 - : Perturbed Replace/Triangulate/Extract RSM (Comp) vs. Survey (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.215	0.231	0.493	0.510	0.102	-0.166	32.404	-23.457
CHEM	check	0.215	0.157	0.493	0.336	0.009	-0.233	3.548	-38.982
MACK	check	0.644	0.240	0.822	0.457	0.089	0.015	12.909	1.605
Mean (check point)		0.358	0.209	0.603	0.434	0.067	0.138	16.287	21.348
Max (check point)		0.644	0.240	0.822	0.510	0.102	0.233	32.404	38.982
Max2 (check point)		0.215	0.231	0.493	0.457	0.089	0.166	12.909	23.457
RMS (check point)		0.411	0.213	0.623	0.440	0.078	0.165	20.242	26.283

Table A.2 - : Perturbed Replace/Triangulate/Extract RSM (Comp) vs. Survey (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.197	0.000	0.448	0.093	-0.066	47.426	-14.825
PH12	MACK	0.000	0.299	0.000	0.648	0.021	0.181	7.033	28.018
CHEM	MACK	0.000	0.229	0.000	0.449	0.079	0.248	34.665	55.212
Mean (check point pair)		0.000	0.242	0.000	0.515	0.065	0.165	29.708	32.685
Max (check point pair)		0.000	0.299	0.000	0.648	0.093	0.248	47.426	55.212
Max2 (check point pair)		0.000	0.229	0.000	0.449	0.079	0.181	34.665	28.018
RMS (check point pair)		0.000	0.245	0.000	0.523	0.072	0.181	34.158	36.756

A.3Oblique Triangulation Results Using Simulated Support Data

Table A.3 - : Oblique Imaging Geometry Detail

Image	1	2	3	4	5	6	7	8	9	10	11	12
Image ID	'1_6'	'1_7'	'1_8'	'1_9'	'2_4'	'2_5'	'2_6'	'2_7'	'3_5'	'3_6'	'3_7'	'3_8'
Number of rows	7776	7840	7904	7840	7840	7776	7872	7840	7776	7840	7840	7936
Number of columns	7712	7776	7840	7776	7776	7712	7808	7776	7712	7776	7776	7872
Ground reference height (m)	214	211	204	196	198	204	205	205	226	222	217	213
Image azimuth angle of north (rad)	0.126	0.138	0.144	0.159	0.162	0.136	0.112	0.163	-2.998	-2.988	-3.001	-2.992
Image azimuth angle of up (rad)	-3.015	-3.003	-2.998	-2.982	-2.979	-3.005	-3.029	-2.979	0.148	0.153	0.140	0.150
Row GSD (LOS-normal) (m)	0.115	0.119	0.126	0.125	0.115	0.112	0.111	0.112	0.107	0.114	0.114	0.117
Column GSD (LOS-normal) (m)	0.115	0.119	0.127	0.125	0.115	0.112	0.111	0.112	0.107	0.114	0.114	0.118
Azimuth angle of imaging locus (rad)	1.565	1.563	1.567	1.569	1.569	1.573	1.575	1.568	1.573	1.576	1.582	1.576
Elevation angle of imaging locus (rad)	0.531	0.528	0.513	0.501	0.533	0.532	0.519	0.528	0.534	0.534	0.529	0.524
Nominal sensor height (m)	511	517	520	502	496	493	487	492	503	518	510	513
Nominal range (m)	588	609	646	637	586	572	568	569	546	581	581	600
Row IFOV (per pixel) (mrad)	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196
Column IFOV (per pixel) (mrad)	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196
Row FOV (full image) (rad)	1.523	1.535	1.548	1.535	1.535	1.523	1.541	1.535	1.523	1.535	1.535	1.554
Column FOV (full image) (rad)	1.512	1.524	1.537	1.524	1.524	1.512	1.531	1.524	1.512	1.525	1.525	1.543

Table A.3 - : Oblique Replace/Triangulate RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
HISC	control	0.193	0.193	0.000	0.393	0.392	-0.178	0.002	0.020	1.181	5.115
PH11	control	0.193	0.193	0.000	0.404	0.406	0.420	0.015	-0.025	7.976	-6.208
LILY	control	0.203	0.203	-0.049	0.428	0.427	-0.210	0.014	0.030	6.889	6.893
BBLL	control	0.196	0.196	-0.051	0.398	0.396	-0.428	0.003	-0.020	1.623	-4.931
STNE	control	0.192	0.192	0.000	0.380	0.379	-0.105	0.005	-0.005	2.860	-1.291
p1_7	tie	0.990	0.990	-0.030	0.608	0.607	-0.066	0.230	0.026	23.214	4.344
p1_6	tie	0.586	0.587	0.085	0.512	0.511	-0.195	0.100	-0.006	17.069	-1.229
p2_8	tie	0.549	0.549	0.055	0.475	0.473	-0.379	0.191	-0.069	34.899	-14.451
p2_7	tie	0.342	0.342	0.176	0.369	0.367	-0.325	0.085	-0.033	24.906	-8.950
p2_6	tie	0.291	0.291	0.172	0.336	0.335	-0.328	0.070	-0.026	23.966	-7.862
p3_6	tie	0.427	0.428	0.187	0.327	0.327	-0.183	0.087	-0.034	20.274	-10.486
p3_5	tie	0.238	0.239	0.252	0.281	0.281	-0.142	0.088	-0.033	37.136	-11.771
p1_5	tie	0.592	0.593	0.135	0.512	0.512	-0.020	0.027	-0.043	4.583	-8.460
p2_5	tie	0.269	0.269	0.261	0.329	0.328	-0.182	0.081	-0.030	30.083	-9.030
p1_4	tie	0.628	0.629	0.207	0.524	0.524	0.134	0.130	-0.076	20.666	-14.490
p2_4	tie	0.314	0.314	0.159	0.368	0.368	-0.082	0.107	-0.045	34.008	-12.123
p3_4	tie	0.236	0.236	0.339	0.299	0.299	0.067	0.101	-0.041	43.024	-13.764
p1_3	tie	1.150	1.152	0.226	0.657	0.660	0.487	0.157	-0.077	13.630	-11.656
p3_3	tie	0.257	0.257	0.351	0.329	0.330	0.335	0.118	-0.052	45.872	-15.698
p2_2	tie	0.546	0.548	0.201	0.499	0.500	0.200	0.148	-0.052	27.149	-10.485
p3_7	tie	0.774	0.776	0.245	0.456	0.457	0.219	0.150	-0.054	19.387	-11.935
p4_7	tie	0.255	0.255	0.118	0.313	0.313	-0.064	0.082	-0.032	31.986	-10.265
p4_5	tie	0.222	0.222	0.090	0.288	0.288	0.209	0.076	-0.034	34.298	-11.752
p4_4	tie	0.200	0.201	0.150	0.306	0.307	0.392	0.076	-0.045	38.039	-14.613
p4_3	tie	0.238	0.238	0.042	0.354	0.356	0.423	0.080	-0.054	33.499	-15.205
p4_2	tie	0.290	0.289	-0.172	0.410	0.411	0.439	0.089	-0.058	30.645	-14.254
p5_4	tie	0.243	0.243	-0.082	0.451	0.453	0.421	0.039	-0.017	16.094	-3.793
p5_3	tie	0.505	0.504	-0.139	0.590	0.593	0.543	0.069	-0.013	13.741	-2.188
p5_5	tie	0.245	0.245	0.082	0.382	0.384	0.340	0.052	-0.038	21.271	-9.916
p5_6	tie	0.275	0.275	0.109	0.394	0.395	0.254	0.061	-0.034	22.332	-8.545
p5_7	tie	0.555	0.557	0.379	0.586	0.593	1.161	0.033	0.052	5.868	8.843
cary	tie	0.242	0.243	0.289	0.281	0.280	-0.178	0.083	-0.034	34.402	-12.246
sand	tie	0.309	0.310	0.162	0.360	0.360	-0.083	0.109	-0.044	35.200	-12.320

owen	tie	0.301	0.301	0.166	0.344	0.343	-0.349	0.056	-0.020	18.762	-5.848
tark	tie	0.334	0.335	0.180	0.346	0.345	-0.318	0.064	-0.025	19.023	-7.254
T19	tie	0.261	0.262	0.191	0.283	0.283	-0.035	0.084	-0.033	32.115	-11.524
t19_tie	tie	0.248	0.248	0.161	0.278	0.278	-0.036	0.080	-0.030	32.280	-10.803
solon	tie	0.249	0.249	0.080	0.315	0.315	-0.032	0.079	-0.031	31.851	-9.822
p4_6	tie	0.243	0.243	0.123	0.299	0.299	0.134	0.078	-0.033	32.021	-10.910
COREC	tie	0.638	0.639	0.141	0.433	0.434	0.069	0.067	-0.030	10.468	-6.991
LAMBERT	tie	0.283	0.284	0.177	0.291	0.291	-0.034	0.077	-0.030	27.313	-10.234
schl	tie	0.267	0.268	0.150	0.313	0.314	0.256	0.094	-0.048	35.056	-15.299
PSYCHO	tie	0.347	0.347	0.058	0.394	0.396	0.431	0.097	-0.054	27.917	-13.597
PU_MALL01	tie	0.383	0.382	-0.131	0.450	0.452	0.378	0.085	-0.053	22.120	-11.739
MSEE	tie	0.383	0.383	0.104	0.364	0.365	0.247	0.060	-0.036	15.751	-9.783
Mean (tie point)		0.393	0.393	0.164	0.393	0.393	0.254	0.091	0.039	26.048	10.362
Max (tie point)		1.150	1.152	0.379	0.657	0.660	1.161	0.230	0.077	45.872	15.698
Max2 (tie point)		0.990	0.990	0.351	0.608	0.607	0.543	0.191	0.076	43.024	15.299
RMS (tie point)		0.446	0.447	0.183	0.405	0.406	0.327	0.099	0.042	27.744	10.924

Table A.3 - : Oblique Replace/Triangulate RSM (Comp) vs. Original Frame (Ref) Relative*

	Ref CE (m)	**Comp CE (m)**	**CE diff %**	**Ref LE (m)**	**Comp LE (m)**	**LE diff %**	**Horiz diff (m)**	**Vert diff (m)**	**Horiz diff %**	**Vert diff %**
Mean (tie point pair)	0.486	0.487	0.144	0.411	0.412	0.298	0.081	0.023	16.304	5.302
Max (tie point pair)	1.455	1.457	0.515	0.971	0.983	1.715	0.421	0.128	54.988	22.329
Max2 (tie point pair)	1.331	1.334	0.513	0.936	0.939	1.637	0.382	0.128	53.408	22.157
RMS (tie point pair)	0.556	0.557	0.172	0.444	0.445	0.406	0.108	0.033	19.067	6.730

*Detailed listing of 990 lines omitted for brevity.

Table A.3 - : Oblique Replace/Triangulate Original Frame (Comp) vs. Truth (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
HISC	control	0.000	0.193	0.000	0.393	0.063	0.076	32.690	19.237
PH11	control	0.000	0.193	0.000	0.404	0.055	-0.345	28.376	-85.234
LILY	control	0.000	0.203	0.000	0.428	0.012	-0.416	5.687	-97.103
BBLL	control	0.000	0.196	0.000	0.398	0.057	-0.201	29.012	-50.642
STNE	control	0.000	0.192	0.000	0.380	0.006	0.098	3.045	25.790
p1_7	tie	0.000	0.990	0.000	0.608	0.263	-0.142	26.545	-23.363
p1_6	tie	0.000	0.586	0.000	0.512	0.162	0.006	27.636	1.229
p2_8	tie	0.000	0.549	0.000	0.475	0.072	0.066	13.108	13.840
p2_7	tie	0.000	0.342	0.000	0.369	0.203	-0.065	59.546	-17.711
p2_6	tie	0.000	0.291	0.000	0.336	0.124	-0.137	42.769	-40.679
p3_6	tie	0.000	0.427	0.000	0.327	0.571	-0.242	133.765	-73.861
p3_5	tie	0.000	0.238	0.000	0.281	0.096	-0.197	40.440	-69.950
p1_5	tie	0.000	0.592	0.000	0.512	0.259	-0.223	43.822	-43.513
p2_5	tie	0.000	0.269	0.000	0.329	0.119	-0.212	44.191	-64.396
p1_4	tie	0.000	0.628	0.000	0.524	0.690	-0.423	109.912	-80.718
p2_4	tie	0.000	0.314	0.000	0.368	0.240	-0.364	76.407	-98.967
p3_4	tie	0.000	0.236	0.000	0.299	0.086	-0.322	36.384	-107.870
p1_3	tie	0.000	1.150	0.000	0.657	0.304	-0.491	26.424	-74.741
p3_3	tie	0.000	0.257	0.000	0.329	0.172	-0.501	66.936	-152.540
p2_2	tie	0.000	0.546	0.000	0.499	0.485	-0.701	88.759	-140.597
p3_7	tie	0.000	0.774	0.000	0.456	0.354	0.144	45.757	31.483
p4_7	tie	0.000	0.255	0.000	0.313	0.030	-0.065	11.704	-20.819
p4_5	tie	0.000	0.222	0.000	0.288	0.077	-0.241	34.748	-83.658
p4_4	tie	0.000	0.200	0.000	0.306	0.026	-0.310	12.771	-101.210
p4_3	tie	0.000	0.238	0.000	0.354	0.013	-0.464	5.599	-131.001
p4_2	tie	0.000	0.290	0.000	0.410	0.023	-0.575	7.968	-140.395
p5_4	tie	0.000	0.243	0.000	0.451	0.079	-0.466	32.475	-103.261
p5_3	tie	0.000	0.505	0.000	0.590	0.144	-0.456	28.424	-77.260
p5_5	tie	0.000	0.245	0.000	0.382	0.041	-0.076	16.735	-19.990
p5_6	tie	0.000	0.275	0.000	0.394	0.179	0.071	65.100	17.951
p5_7	tie	0.000	0.555	0.000	0.586	0.323	0.307	58.222	52.407
cary	tie	0.000	0.242	0.000	0.281	0.102	-0.107	42.274	-38.234
sand	tie	0.000	0.309	0.000	0.360	0.258	-0.312	83.407	-86.654

owen	tie	0.000	0.301	0.000	0.344	0.203	-0.091	67.681	-26.622
tark	tie	0.000	0.334	0.000	0.346	0.086	-0.087	25.745	-25.145
T19	tie	0.000	0.261	0.000	0.283	0.090	-0.117	34.380	-41.393
t19_tie	tie	0.000	0.248	0.000	0.278	0.014	-0.133	5.786	-47.893
solon	tie	0.000	0.249	0.000	0.315	0.006	-0.095	2.324	-30.070
p4_6	tie	0.000	0.243	0.000	0.299	0.086	-0.204	35.325	-68.440
COREC	tie	0.000	0.638	0.000	0.433	0.120	-0.231	18.749	-53.346
LAMBERT	tie	0.000	0.283	0.000	0.291	0.134	-0.012	47.151	-4.087
schl	tie	0.000	0.267	0.000	0.313	0.076	-0.259	28.382	-82.593
PSYCHO	tie	0.000	0.347	0.000	0.394	0.030	-0.489	8.580	-124.176
PU_MALL01	tie	0.000	0.383	0.000	0.450	0.006	-0.566	1.542	-125.900
MSEE	tie	0.000	0.383	0.000	0.364	0.080	-0.274	20.975	-75.240
Mean (tie point)		0.000	0.393	0.000	0.393	0.161	0.256	39.461	65.330
Max (tie point)		0.000	1.150	0.000	0.657	0.690	0.701	133.765	152.540
Max2 (tie point)		0.000	0.990	0.000	0.608	0.571	0.575	109.912	140.597
RMS (tie point)		0.000	0.446	0.000	0.405	0.221	0.310	49.126	77.108

Table A.3 - : Oblique Replace/Triangulate Original Frame (Comp) vs. Truth (Ref) Relative*

	Ref CE (m)	**Comp CE (m)**	**Ref LE (m)**	**Comp LE (m)**	**Horiz diff (m)**	**Vert diff (m)**	**Horiz diff %**	**Vert diff %**
Mean (tie point pair)	0.000	0.472	0.000	0.401	0.227	0.249	51.119	63.179
Max (tie point pair)	0.000	1.455	0.000	0.971	1.035	1.008	182.176	168.968
Max2 (tie point pair)	0.000	1.331	0.000	0.971	1.035	1.008	178.827	160.020
RMS (tie point pair)	0.000	0.543	0.000	0.434	0.289	0.309	60.642	74.155

*Detailed listing of 990 lines omitted for brevity.

Table A.3 - : Oblique Replace/Triangulate RSM (Comp) vs. Truth (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
HISC	control	0.000	0.193	0.000	0.392	0.064	0.096	33.327	24.395
PH11	control	0.000	0.193	0.000	0.406	0.070	-0.370	36.348	-91.059
LILY	control	0.000	0.203	0.000	0.427	0.004	-0.386	2.172	-90.400
BBLL	control	0.000	0.196	0.000	0.396	0.054	-0.221	27.424	-55.811
STNE	control	0.000	0.192	0.000	0.379	0.011	0.093	5.737	24.525
p1_7	tie	0.000	0.990	0.000	0.607	0.053	-0.116	5.391	-19.032
p1_6	tie	0.000	0.587	0.000	0.511	0.242	0.000	41.289	0.000
p2_8	tie	0.000	0.549	0.000	0.473	0.261	-0.003	47.538	-0.613
p2_7	tie	0.000	0.342	0.000	0.367	0.285	-0.098	83.167	-26.748
p2_6	tie	0.000	0.291	0.000	0.335	0.194	-0.163	66.618	-48.700
p3_6	tie	0.000	0.428	0.000	0.327	0.658	-0.276	153.747	-84.502
p3_5	tie	0.000	0.239	0.000	0.281	0.184	-0.230	77.137	-81.838
p1_5	tie	0.000	0.593	0.000	0.512	0.280	-0.266	47.203	-51.984
p2_5	tie	0.000	0.269	0.000	0.328	0.198	-0.242	73.713	-73.561
p1_4	tie	0.000	0.629	0.000	0.524	0.818	-0.499	130.099	-95.081
p2_4	tie	0.000	0.314	0.000	0.368	0.343	-0.409	109.275	-111.181
p3_4	tie	0.000	0.236	0.000	0.299	0.187	-0.363	79.080	-121.553
p1_3	tie	0.000	1.152	0.000	0.660	0.460	-0.568	39.897	-85.978
p3_3	tie	0.000	0.257	0.000	0.330	0.289	-0.553	112.114	-167.677
p2_2	tie	0.000	0.548	0.000	0.500	0.633	-0.754	115.602	-150.780
p3_7	tie	0.000	0.776	0.000	0.457	0.205	0.089	26.357	19.505
p4_7	tie	0.000	0.255	0.000	0.313	0.097	-0.097	37.962	-31.104
p4_5	tie	0.000	0.222	0.000	0.288	0.148	-0.274	66.783	-95.212
p4_4	tie	0.000	0.201	0.000	0.307	0.059	-0.354	29.323	-115.370
p4_3	tie	0.000	0.238	0.000	0.356	0.092	-0.518	38.681	-145.590
p4_2	tie	0.000	0.289	0.000	0.411	0.078	-0.634	26.891	-153.973
p5_4	tie	0.000	0.243	0.000	0.453	0.117	-0.483	48.234	-106.605
p5_3	tie	0.000	0.504	0.000	0.593	0.209	-0.469	41.481	-79.018
p5_5	tie	0.000	0.245	0.000	0.384	0.056	-0.114	22.913	-29.804
p5_6	tie	0.000	0.275	0.000	0.395	0.139	0.037	50.625	9.383
p5_7	tie	0.000	0.557	0.000	0.593	0.351	0.359	63.039	60.547
cary	tie	0.000	0.243	0.000	0.280	0.185	-0.142	76.365	-50.571
sand	tie	0.000	0.310	0.000	0.360	0.367	-0.357	118.275	-99.056

owen	tie	0.000	0.301	0.000	0.343	0.258	-0.112	85.810	-32.584
tark	tie	0.000	0.335	0.000	0.345	0.149	-0.112	44.544	-32.502
T19	tie	0.000	0.262	0.000	0.283	0.164	-0.150	62.758	-52.935
t19_tie	tie	0.000	0.248	0.000	0.278	0.082	-0.163	32.892	-58.718
solon	tie	0.000	0.249	0.000	0.315	0.084	-0.125	33.529	-39.905
p4_6	tie	0.000	0.243	0.000	0.299	0.150	-0.237	61.473	-79.245
COREC	tie	0.000	0.639	0.000	0.434	0.092	-0.261	14.355	-60.295
LAMBERT	tie	0.000	0.284	0.000	0.291	0.058	-0.042	20.433	-14.325
schl	tie	0.000	0.268	0.000	0.314	0.028	-0.306	10.344	-97.643
PSYCHO	tie	0.000	0.347	0.000	0.396	0.125	-0.543	36.022	-137.181
PU_MALL01	tie	0.000	0.382	0.000	0.452	0.079	-0.619	20.681	-137.121
MSEE	tie	0.000	0.383	0.000	0.365	0.115	-0.309	30.080	-84.814
Mean (tie point)		0.000	0.393	0.000	0.393	0.214	0.286	57.043	73.556
Max (tie point)		0.000	1.152	0.000	0.660	0.818	0.754	153.747	167.677
Max2 (tie point)		0.000	0.990	0.000	0.607	0.658	0.634	130.099	153.973
RMS (tie point)		0.000	0.447	0.000	0.406	0.274	0.345	66.798	86.241

Table A.3 - : Oblique Replace/Triangulate RSM (Comp) vs. Truth (Ref) Relative*

	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
Mean (tie point pair)	0.000	0.473	0.000	0.402	0.261	0.262	59.057	65.981
Max (tie point pair)	0.000	1.457	0.000	0.983	1.063	1.112	187.959	175.584
Max2 (tie point pair)	0.000	1.334	0.000	0.983	1.053	1.112	184.494	166.634
RMS (tie point pair)	0.000	0.543	0.000	0.435	0.329	0.327	69.457	77.527

*Detailed listing of 990 lines omitted for brevity.

Table A.3 - : Oblique Replace/Triangulate/Extract RSM (Comp) vs. Original Frame (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.250	0.251	0.320	0.302	0.302	-0.033	0.101	-0.036	40.512	-11.769
CHEM	check	0.302	0.302	0.066	0.409	0.410	0.440	0.084	-0.057	27.872	-14.020
MACK	check	0.534	0.535	0.300	0.409	0.410	0.244	0.112	-0.041	20.891	-9.971
Mean (check point)		0.362	0.363	0.229	0.373	0.374	0.239	0.099	0.045	29.758	11.920
Max (check point)		0.534	0.535	0.320	0.409	0.410	0.440	0.112	0.057	40.512	14.020
Max2 (check point)		0.302	0.302	0.300	0.409	0.410	0.244	0.101	0.041	27.872	11.769
RMS (check point)		0.382	0.383	0.256	0.377	0.378	0.291	0.100	0.046	30.846	12.034

Table A.3 - : Oblique Replace/Triangulate/Extract RSM (Comp) vs. Original Frame (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	CE diff %	Ref LE (m)	Comp LE (m)	LE diff %	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.311	0.311	0.129	0.377	0.379	0.424	0.060	-0.022	19.304	-5.754
PH12	MACK	0.505	0.506	0.277	0.398	0.400	0.503	0.024	-0.005	4.821	-1.307
CHEM	MACK	0.556	0.557	0.216	0.552	0.555	0.544	0.084	0.017	15.045	2.991
Mean (check point pair)		0.457	0.458	0.207	0.442	0.444	0.490	0.056	0.014	13.056	3.351
Max (check point pair)		0.556	0.557	0.277	0.552	0.555	0.544	0.084	0.022	19.304	5.754
Max2 (check point pair)		0.505	0.506	0.216	0.398	0.400	0.503	0.060	0.017	15.045	2.991
RMS (check point pair)		0.469	0.470	0.216	0.449	0.451	0.493	0.061	0.016	14.402	3.820

Table A.3 - : Oblique Replace/Triangulate/Extract Original Frame (Comp) vs. Truth (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.000	0.250	0.000	0.302	0.132	-0.254	52.678	-84.000
CHEM	check	0.000	0.302	0.000	0.409	0.049	-0.523	16.196	-127.942
MACK	check	0.000	0.534	0.000	0.409	0.679	0.295	127.256	72.165
Mean (check point)		0.000	0.362	0.000	0.373	0.287	0.357	65.376	94.702
Max (check point)		0.000	0.534	0.000	0.409	0.679	0.523	127.256	127.942
Max2 (check point)		0.000	0.302	0.000	0.409	0.132	0.295	52.678	84.000
RMS (check point)		0.000	0.382	0.000	0.377	0.400	0.376	80.065	97.695

Table A.3 - : Oblique Replace/Triangulate/Extract Original Frame (Comp) vs. Truth (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.311	0.000	0.377	0.171	-0.269	54.920	-71.281
PH12	MACK	0.000	0.505	0.000	0.398	0.772	0.549	153.077	138.110
CHEM	MACK	0.000	0.556	0.000	0.552	0.631	0.818	113.371	148.332
Mean (check point pair)		0.000	0.457	0.000	0.442	0.525	0.545	107.122	119.241
Max (check point pair)		0.000	0.556	0.000	0.552	0.772	0.818	153.077	148.332
Max2 (check point pair)		0.000	0.505	0.000	0.398	0.631	0.549	113.371	138.110
RMS (check point pair)		0.000	0.469	0.000	0.449	0.584	0.590	114.458	124.040

Table A.3 - : Oblique Replace/Triangulate/Extract RSM (Comp) vs. Truth (Ref) Absolute

POINT ID	TYPE	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	check	0.000	0.251	0.000	0.302	0.224	-0.290	89.230	-95.800
CHEM	check	0.000	0.302	0.000	0.410	0.062	-0.580	20.630	-141.340
MACK	check	0.000	0.535	0.000	0.410	0.568	0.255	106.118	62.043
Mean (check point)		0.000	0.363	0.000	0.374	0.285	0.375	71.993	99.728
Max (check point)		0.000	0.535	0.000	0.410	0.568	0.580	106.118	141.340
Max2 (check point)		0.000	0.302	0.000	0.410	0.224	0.290	89.230	95.800
RMS (check point)		0.000	0.383	0.000	0.378	0.354	0.402	80.929	104.887

Table A.3 - : Oblique Replace/Triangulate/Extract RSM (Comp) vs. Truth (Ref) Relative

POINT ID	POINT ID	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)	Horiz diff %	Vert diff %
PH12	CHEM	0.000	0.311	0.000	0.379	0.193	-0.291	62.001	-76.710
PH12	MACK	0.000	0.506	0.000	0.400	0.761	0.544	150.491	136.118
CHEM	MACK	0.000	0.557	0.000	0.555	0.573	0.835	102.831	150.505
Mean (check point pair)		0.000	0.458	0.000	0.444	0.509	0.556	105.108	121.111
Max (check point pair)		0.000	0.557	0.000	0.555	0.761	0.835	150.491	150.505
Max2 (check point pair)		0.000	0.506	0.000	0.400	0.573	0.544	102.831	136.118
RMS (check point pair)		0.000	0.470	0.000	0.451	0.561	0.599	111.154	125.252